MENU2016@Kyoto, July 30,2016

Physics in J-PARC Hadron-hall extension

Hiroyuki Noumi
RCNP, Osaka Univ.

This talk is mostly based on recent discussion of the WG on the Hadron Hall Extension under the Hadron User Association.

(DRAFT)
J-PARC ハドロン実験施設の拡張計画

平成 28 年 5 月 20 日

J-PARC ハドロン実験施設拡張検討委員会

A write paper is coming soon.

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- Overview of the Hadron Hall extension
- Hadron Physics Program
  - Hadron Spectroscopy, Hadron Property in Matter
- Nuclear Physics Program
  - High density Hadronic Matter, Nuclear Forces
- Particle Physics Program
  - Beyond SM, Matter-Antimatter asymmetry

Hadron Nuclear Physics at J-PARC

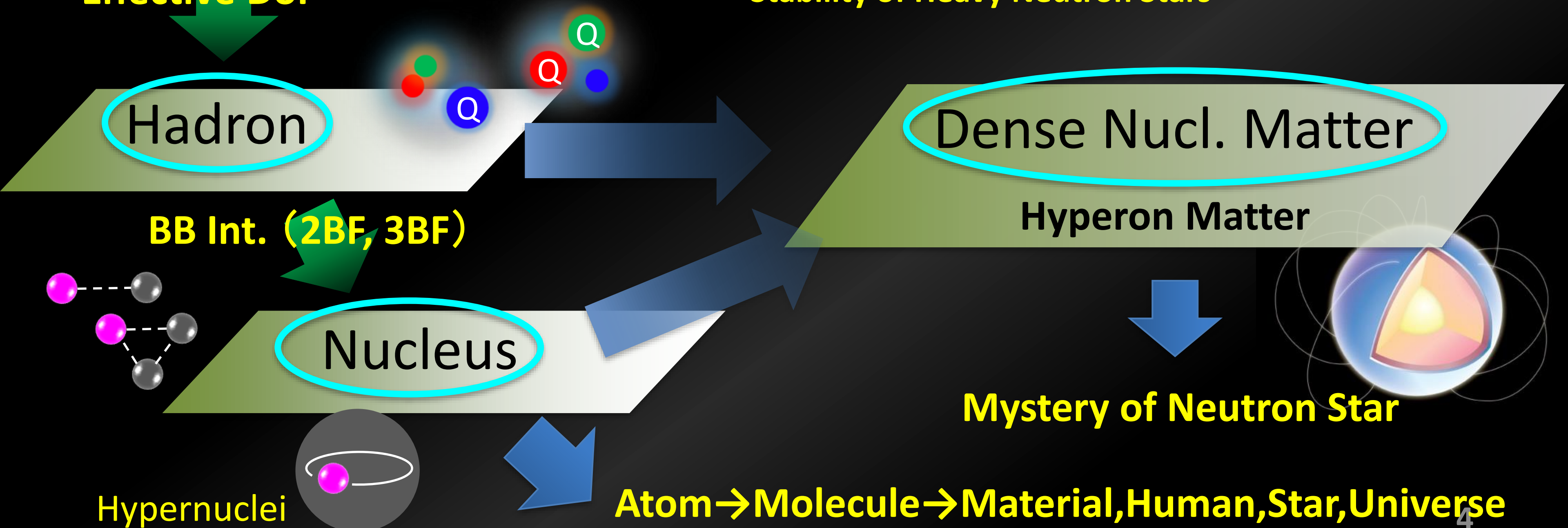
Matter Evolution from Quark to Hadron, Nucleus, and Neutron Star

How QCD works in Hadron?

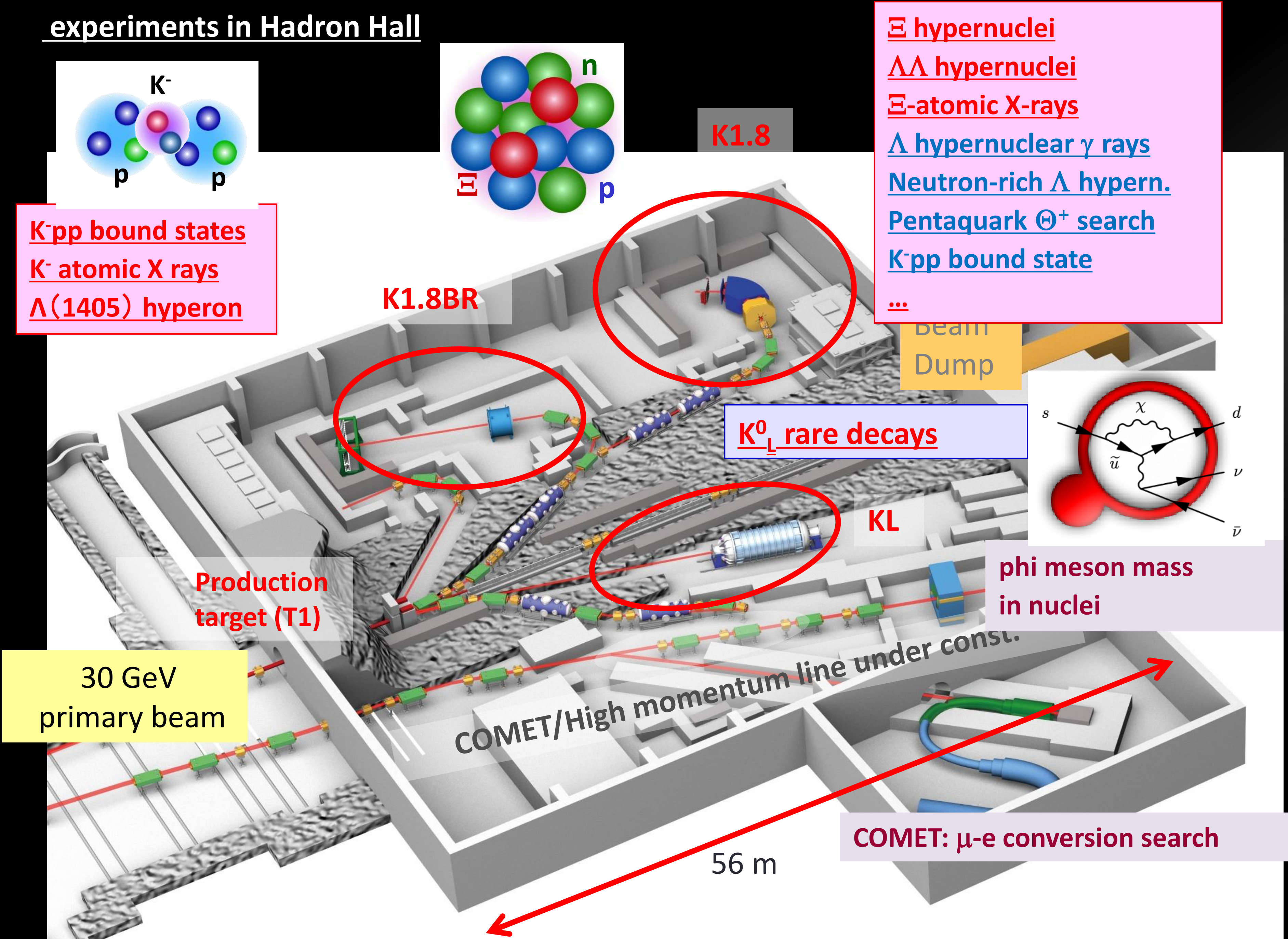
- Effective DoF (building blocks) to describe hadrons
- Change of Hadron Properties in Matter

How are nuclei formed?

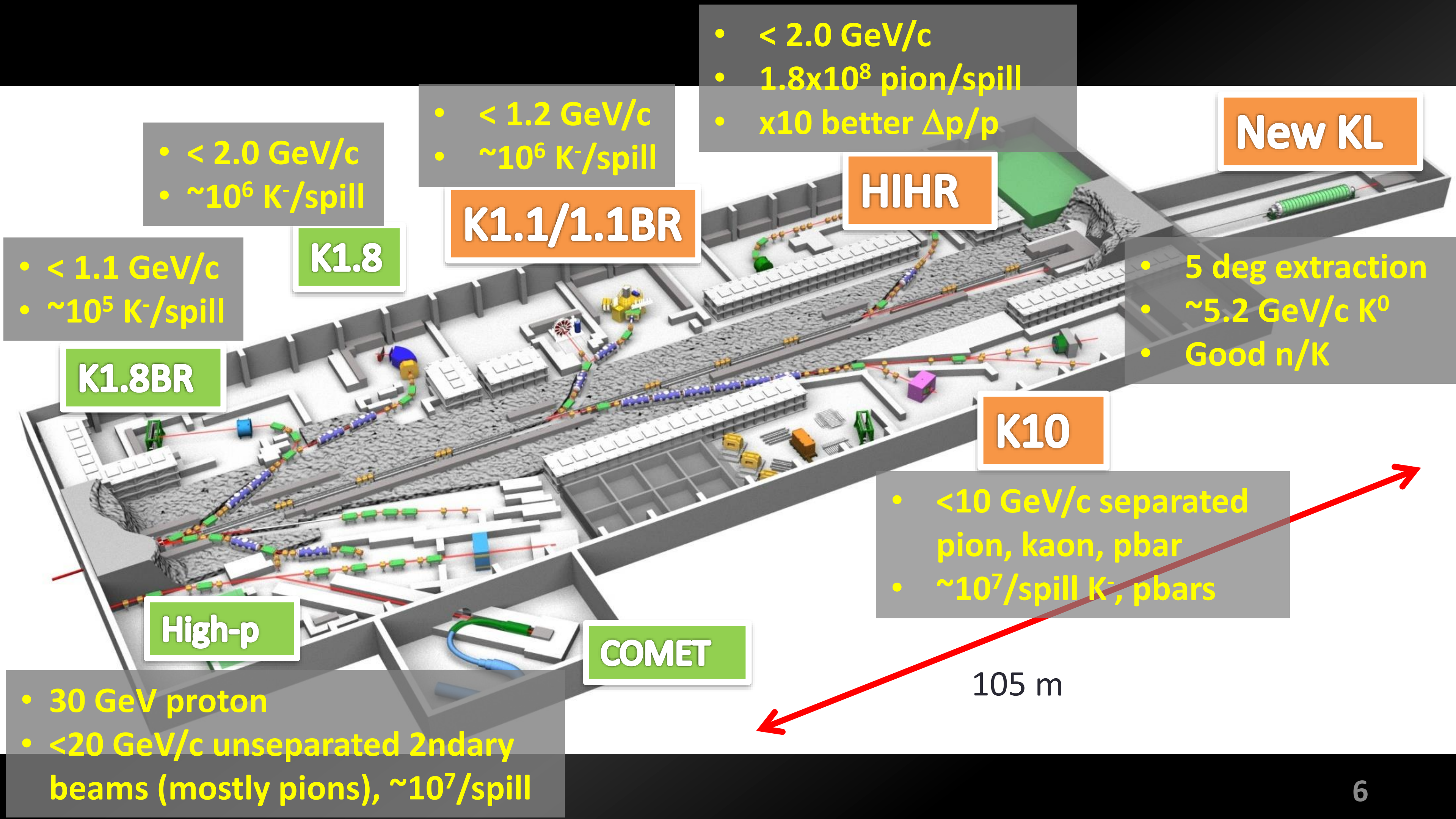
- Extended Nuclear Force : Baryon-Baryon Int.
- Stability of Heavy Neutron Stars



experiments in Hadron Hall

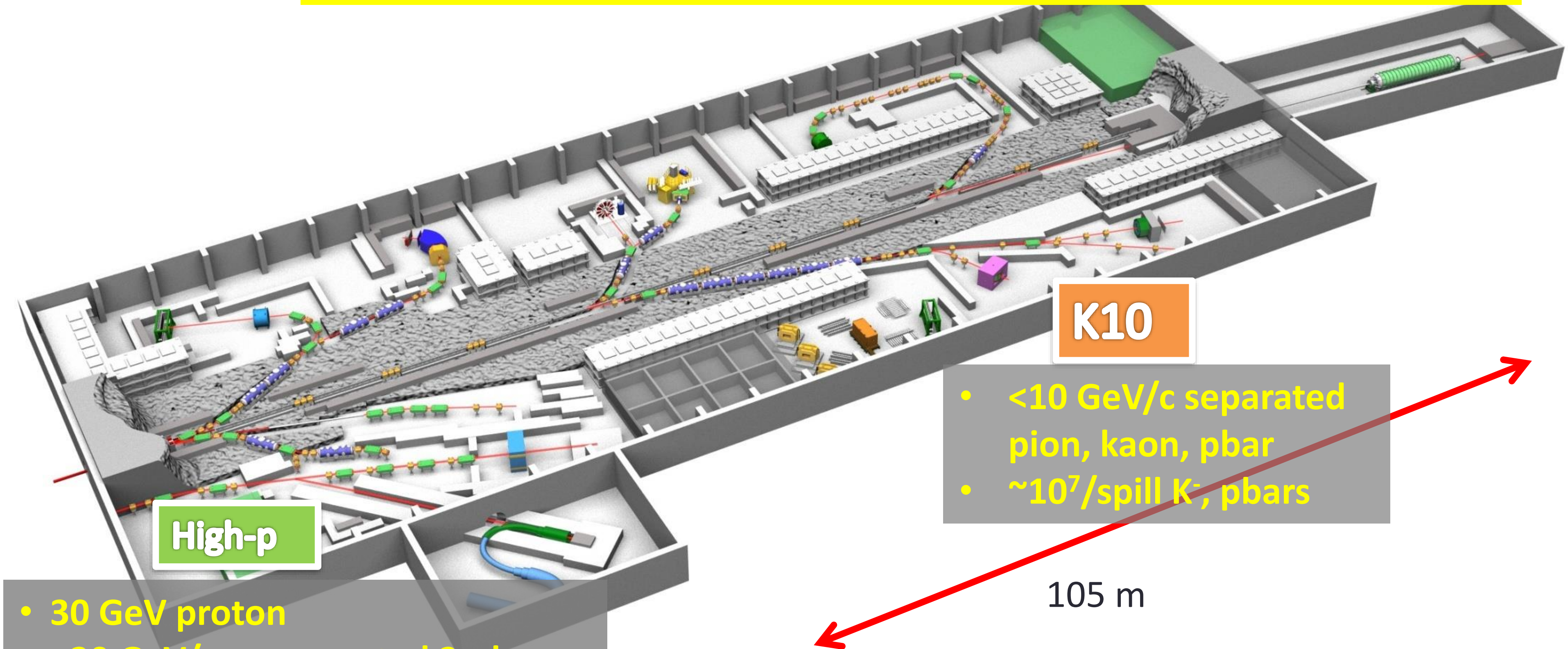


Overview: Extension of the Hadron Experimental Facility



Hadron Physics Programs

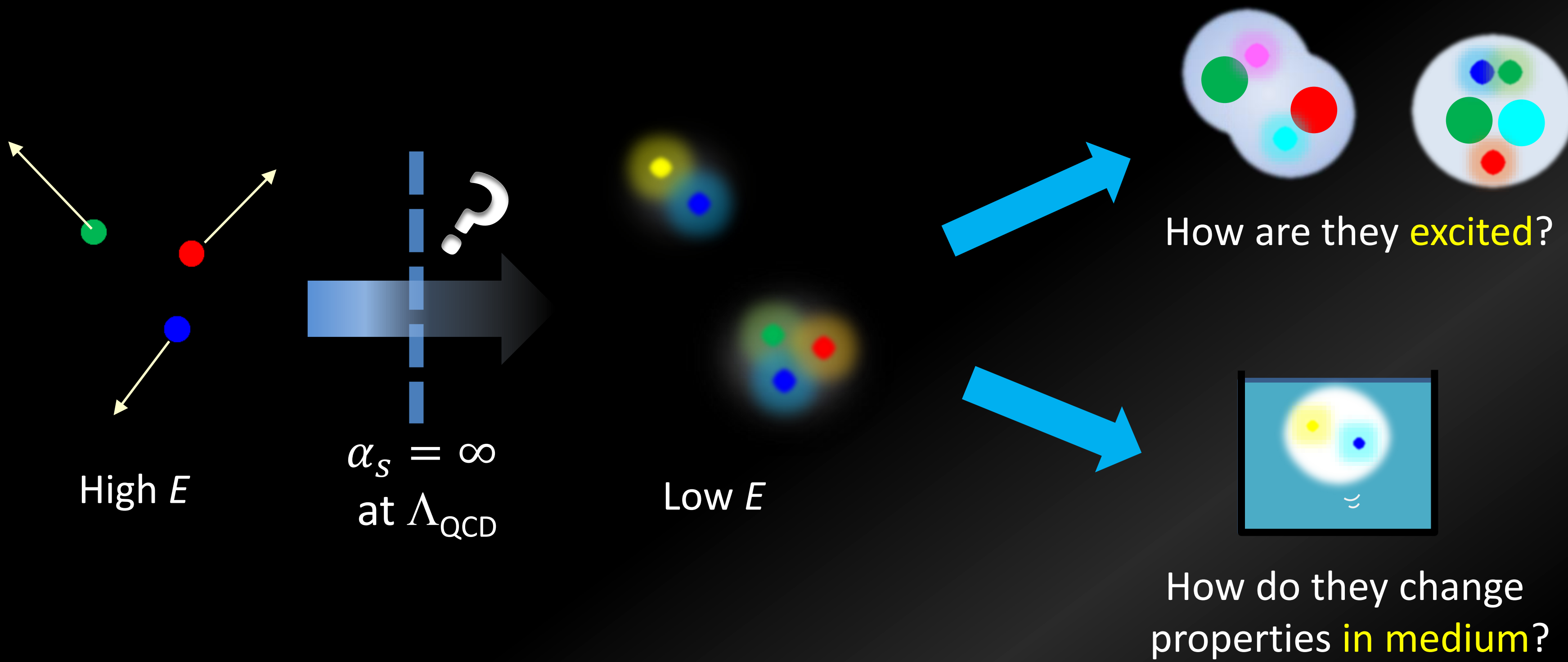
- Structure of Hadrons w/ charm/multi-strange quarks
- Hadron Properties in Nuclear Medium



K10
- <10 GeV/c separated pion, kaon, pbar
- ~10^7/spill K^-, pbars

High-p
- 30 GeV proton
- <20 GeV/c unseparated 2ndary beams (mostly pions), ~10^7/spill

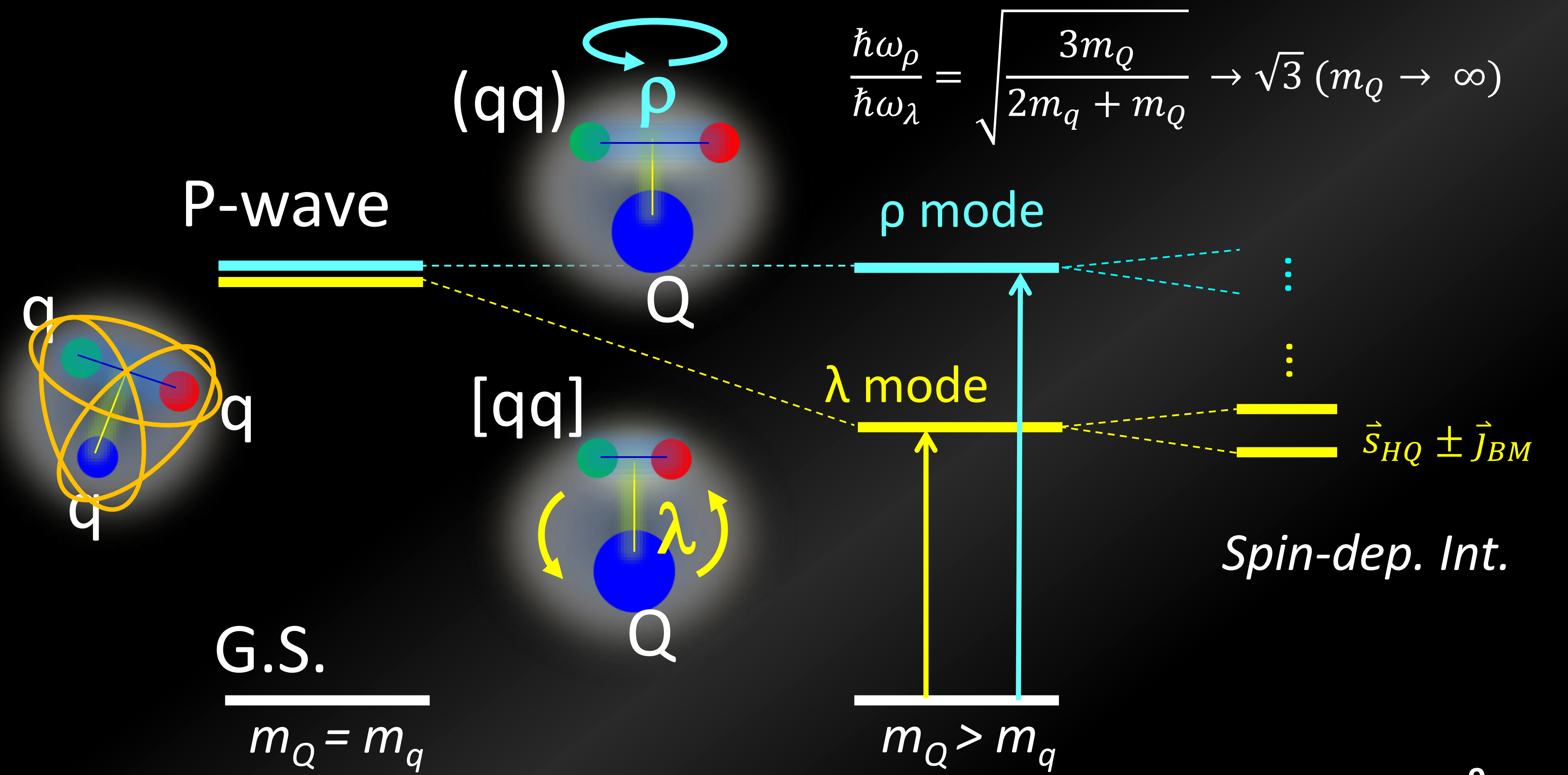
Hadron Physics at J-PARC



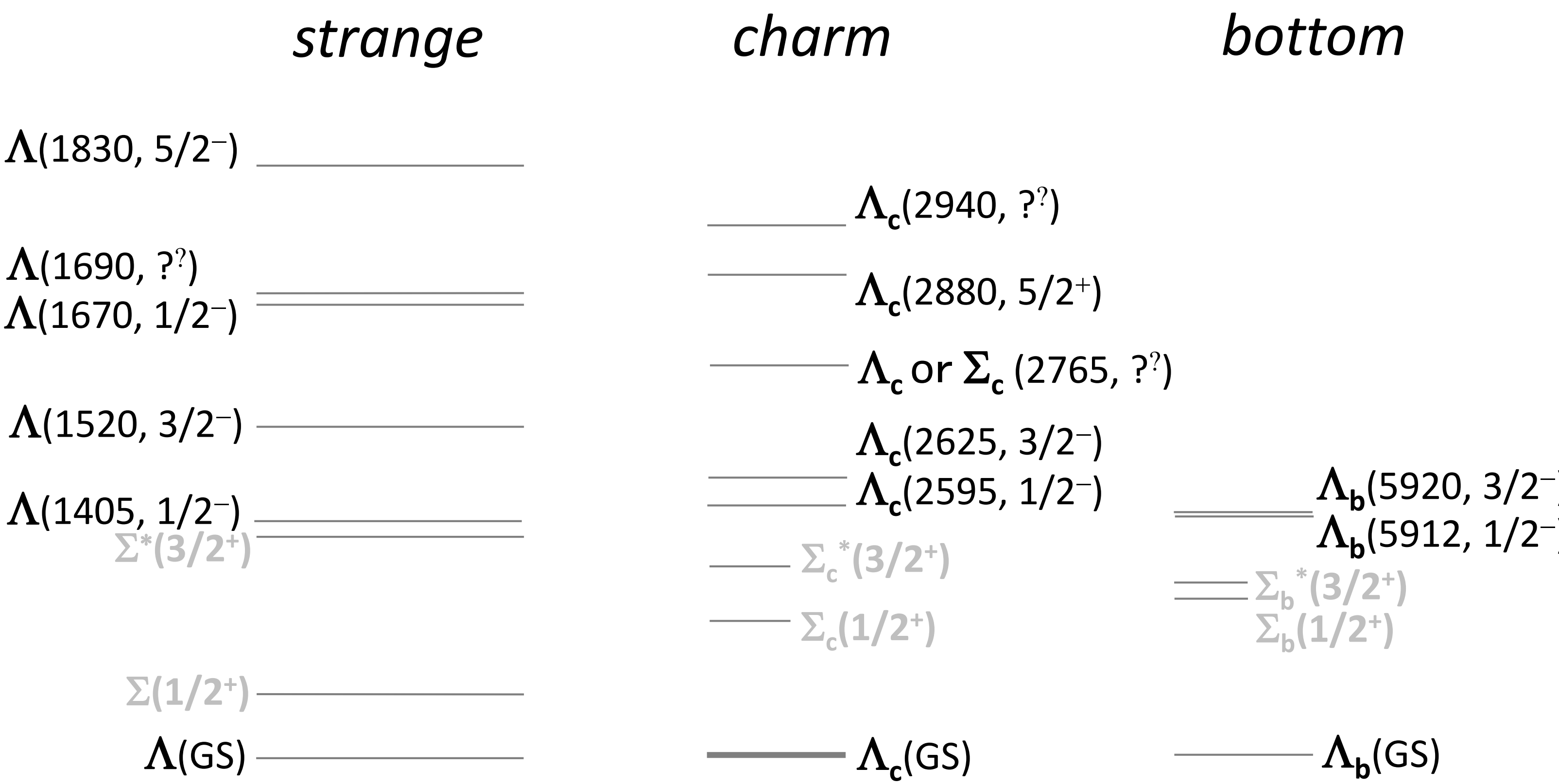
Quasi-Particles (= Effective DoF) emerging at Low E describe hadron properties effectively.

Baryon Spectroscopy w/ Heavy Quark

- Disentangle Quark Correlations in Baryon
  - λ and ρ motions split (Isotope Shift)



Lambda Baryons (P-wave)



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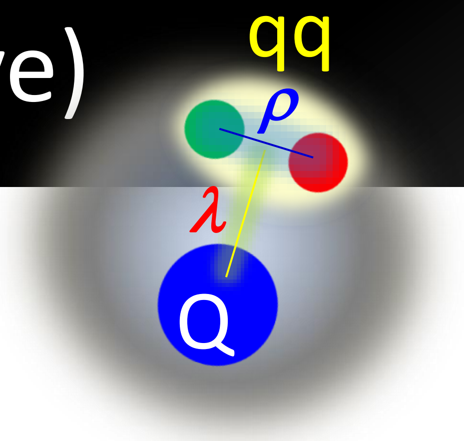
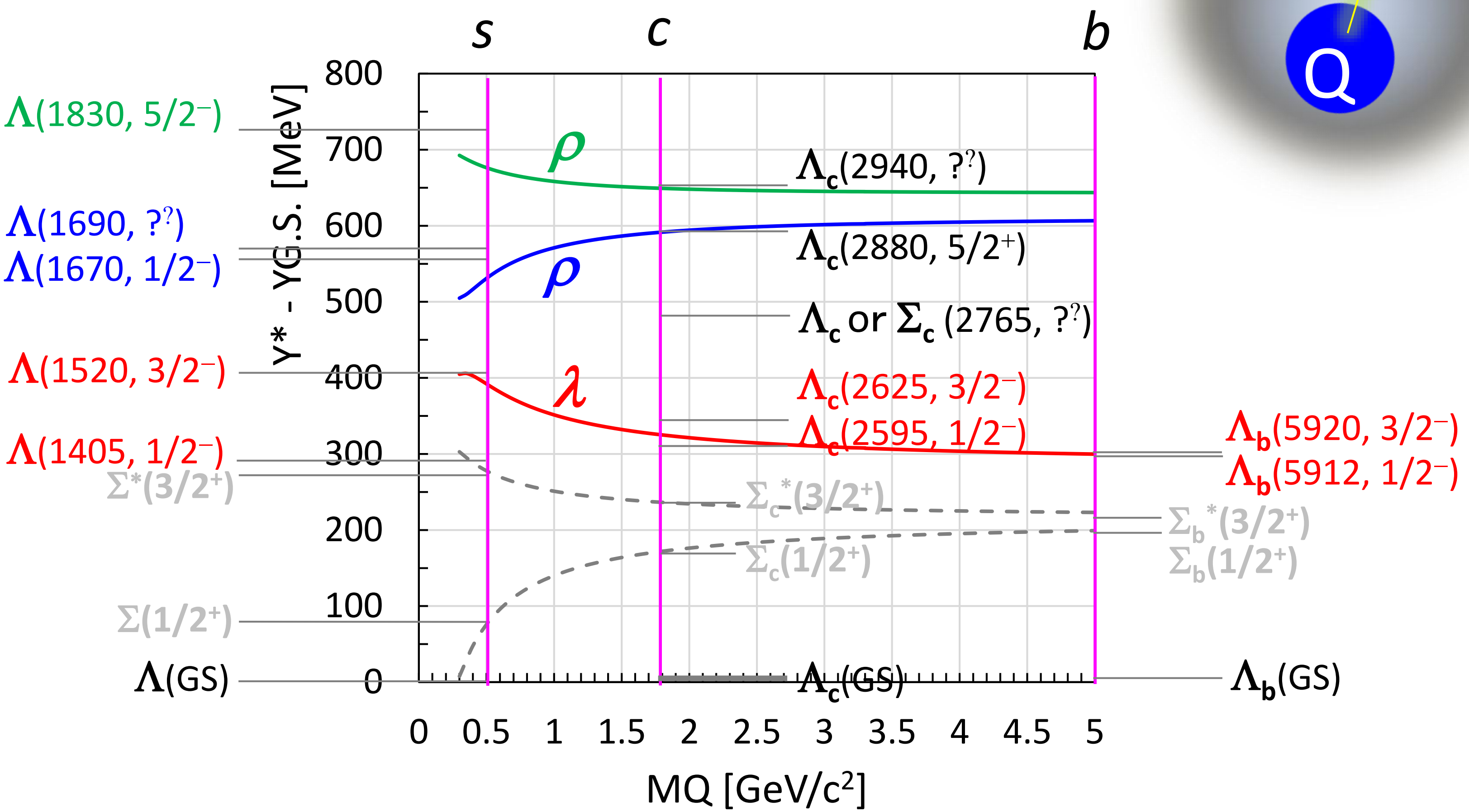
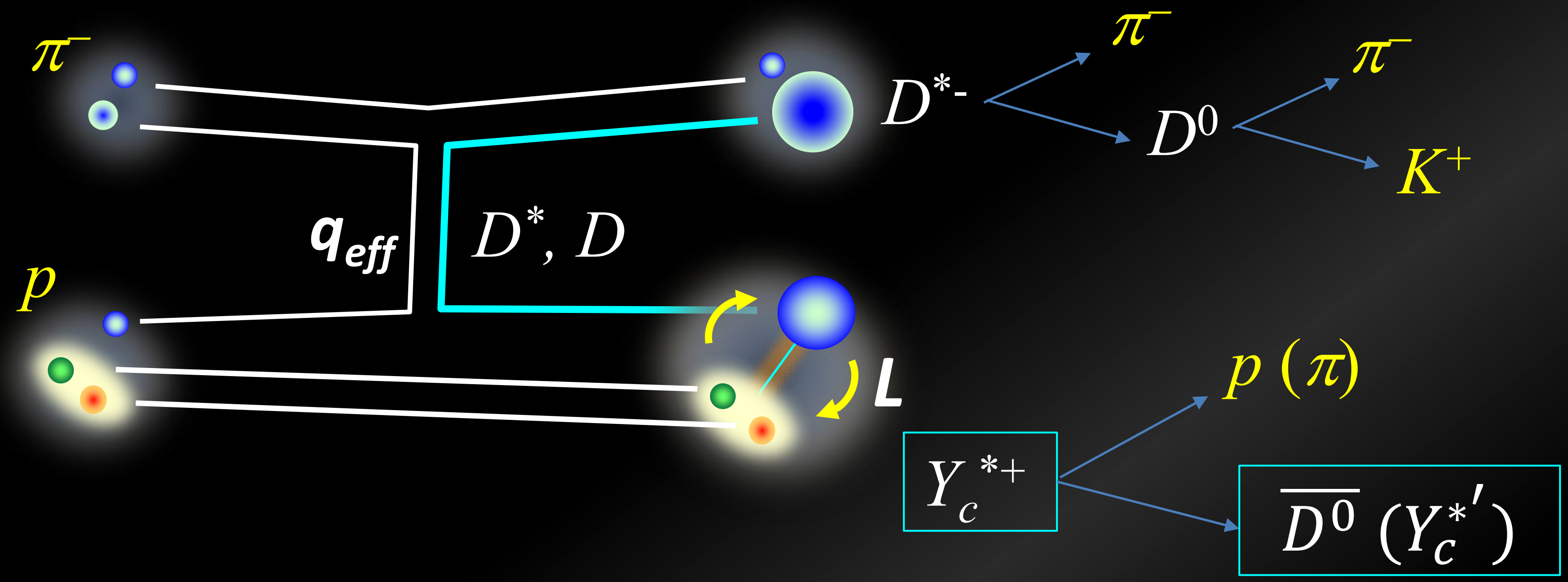




non-rel. QM: $H=H_0+V_{conf}+V_{SS}+V_{LS}+V_T$

ρ–λ mixing (cal. By T. Yoshida)

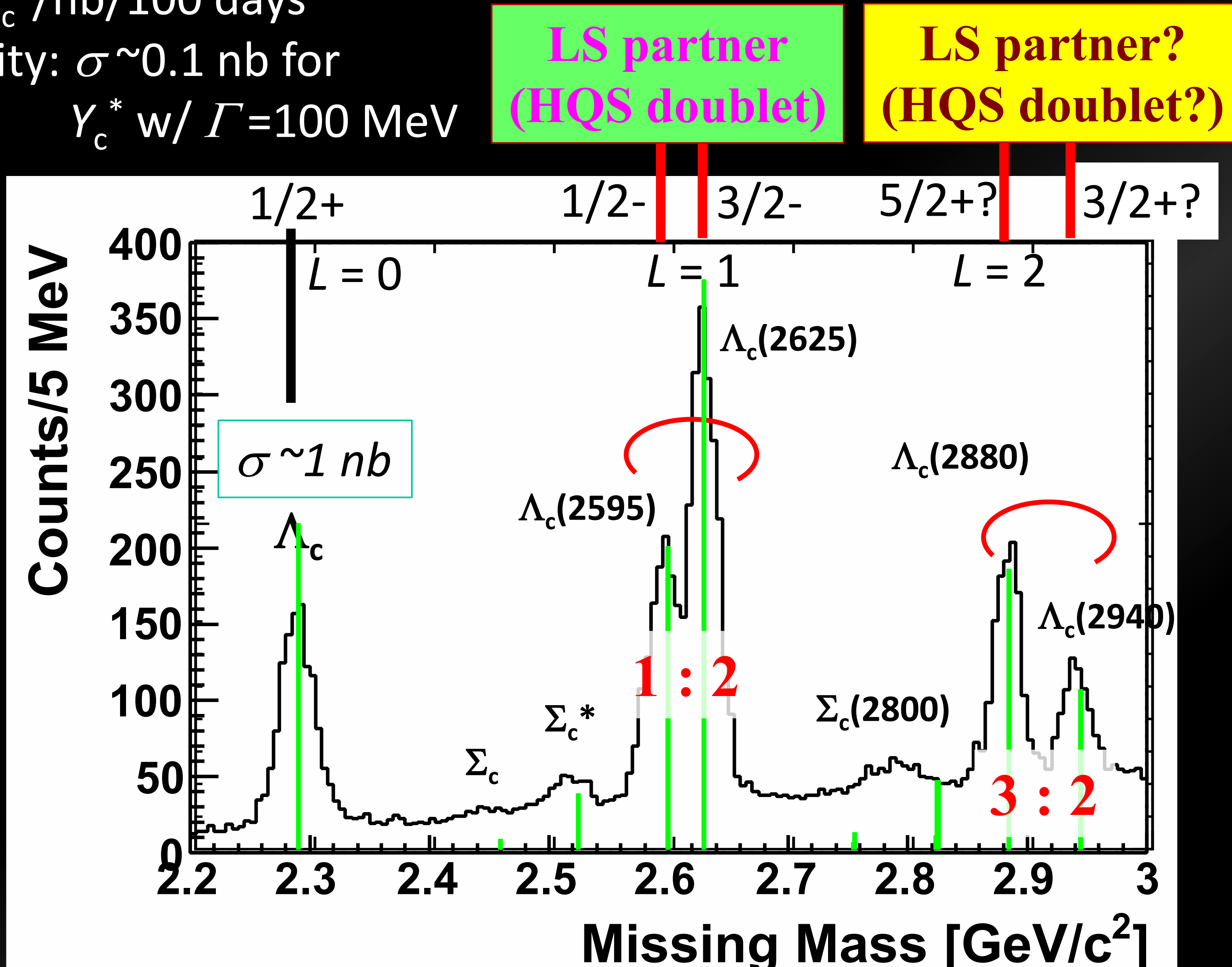
Charmed Baryon Spectroscopy Using Missing Mass Techniques



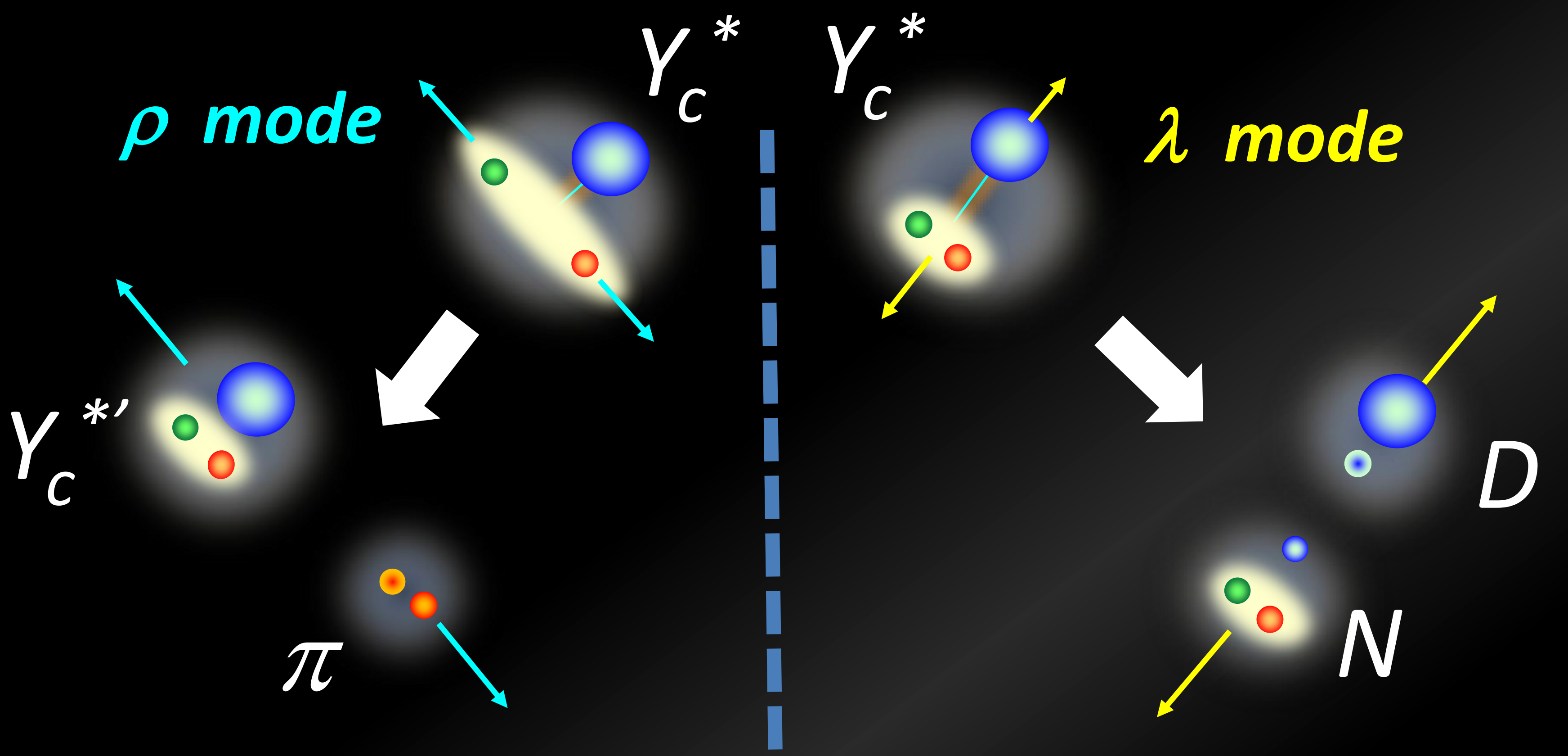
- ✓ Production and Decay reflect [qq] correlation…
- ✓ C.S. DOES NOT go down at higher *L* when q_{eff}>1 GeV/c.

Missing Mass Spectrum (Sim.)

- ~1000 Y_c^*/nb/100 days
- Sensitivity: σ~0.1 nb for Y_c^* w/ Γ=100 MeV



Y_c^* Decay Pattern

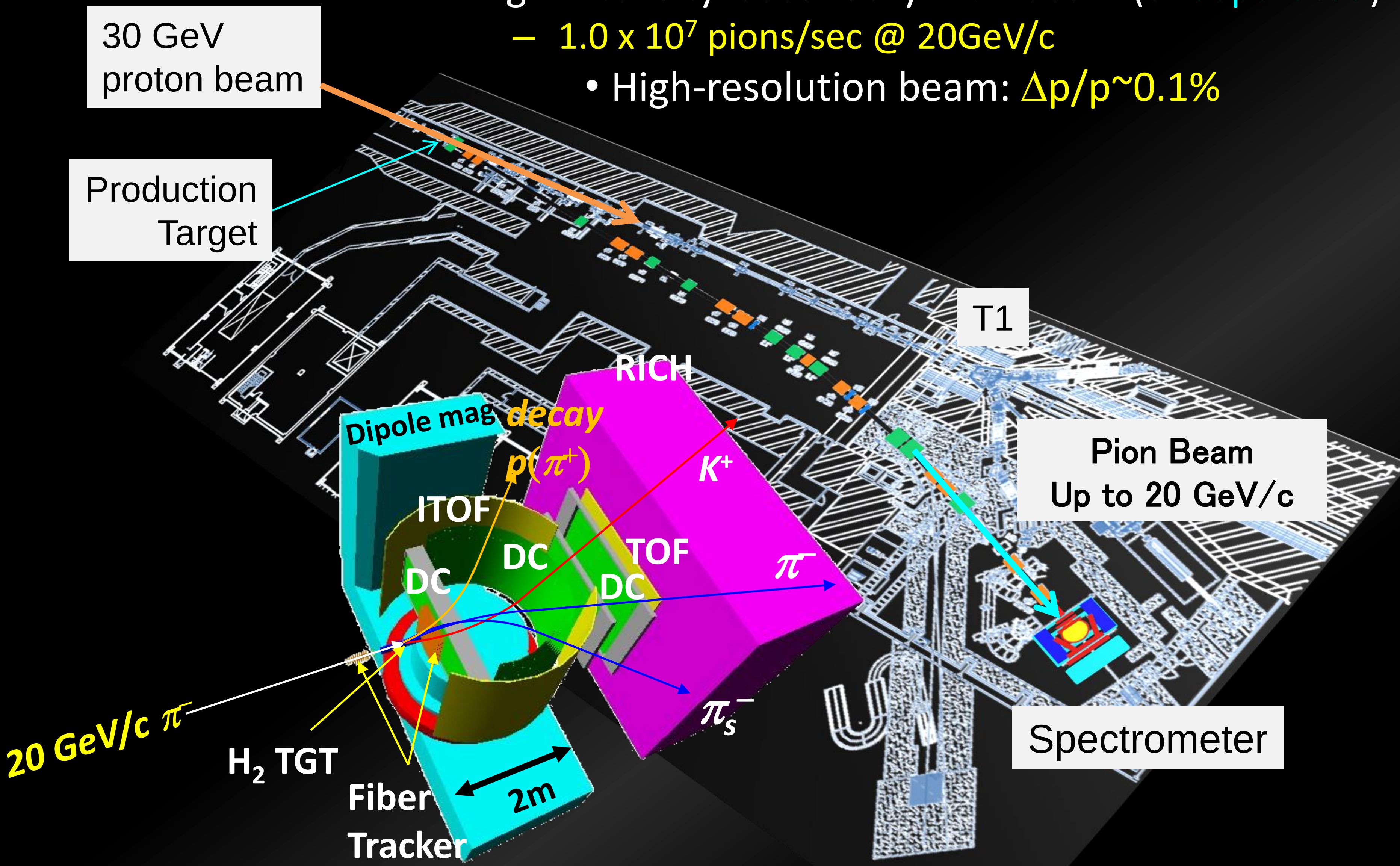


$\Gamma(Y\pi) > \Gamma(DN)$

$\Gamma(DN) > \Gamma(Y\pi)$

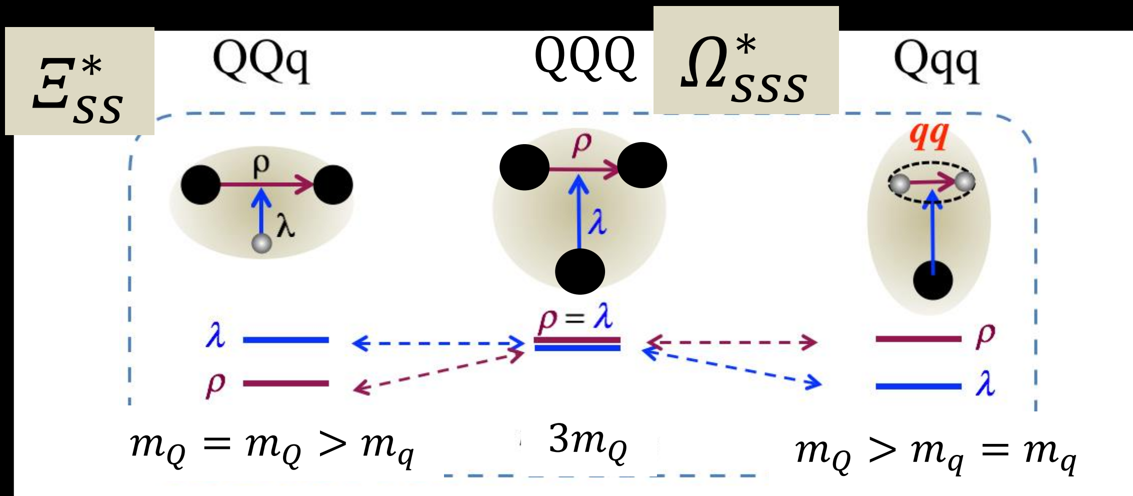
High-res., High-momentum Beam Line

- High-intensity secondary Pion beam (unseparated)
  - 1.0×10^7 pions/sec @ 20GeV/c
    - High-resolution beam: $\Delta p/p$~0.1%



Disentangle Quark Correlations in Baryon w/ HQ

- ρ/λ mode separation in excited states reveals quark correlations.

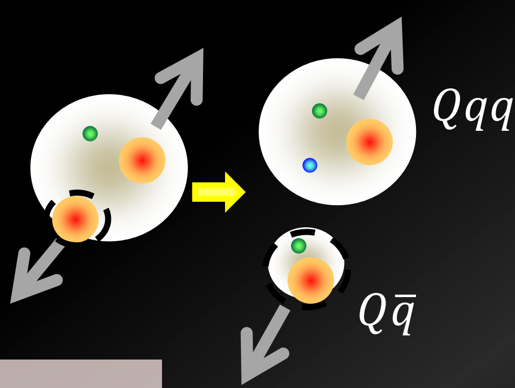


Level crossing between QQq and Qqq

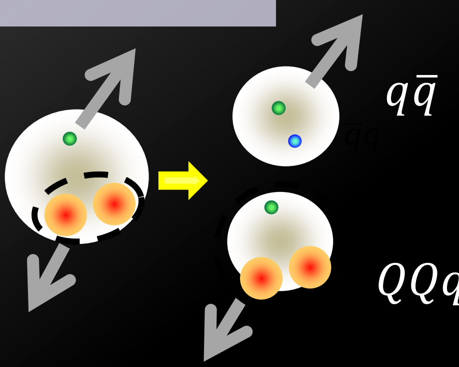
- Decay branches reflect the quark correlations.

$\Xi^* \to \Xi\pi$

ρ mode



λ mode

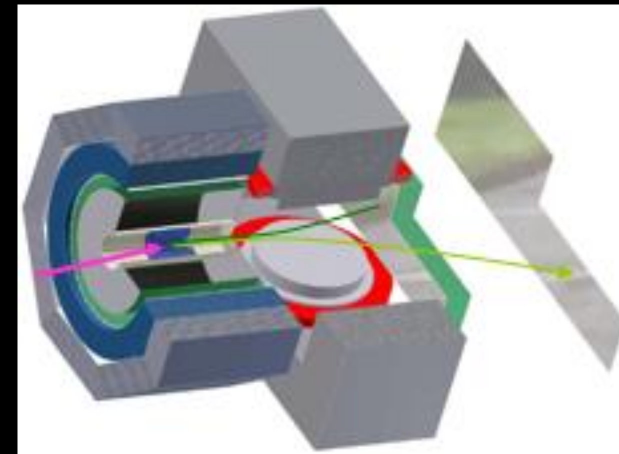


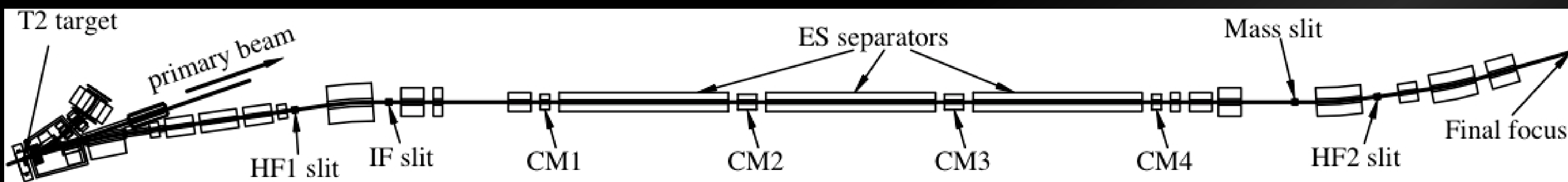
$\Xi^* \to \Lambda K, \Sigma K$

Different decay branches for different correlations

Facility: K10

- Ξ*, Ω*, D productions
- 3-stage electro-static separators:
  - 9 m each, 75kV/cm
- Length : 82.8 m





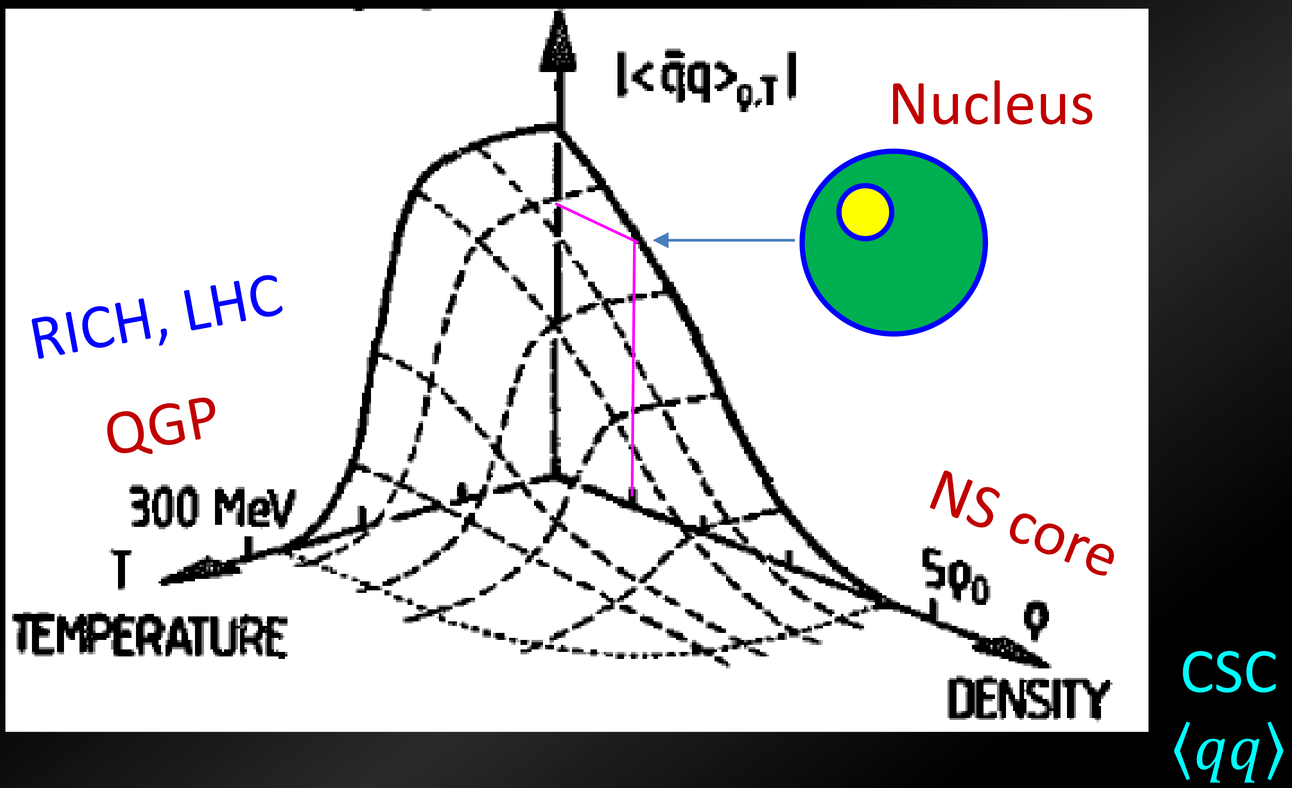
25 kW loss@T2 target

	K^- 4GeV/c	pbar 4GeV/c	pbar 6GeV/c
Acceptance (msr-%)	0.33	1.2	0.55
Beam Intensity (/spill)	1.7×10^6	1.6×10^7	7.8×10^6
Purity	1.1:1	81:1	1:3.4

Spontaneous Chiral Symmetry Breaking

- Qualitative impression how $\langle \bar{q}q \rangle$ behaves with ρ and T.

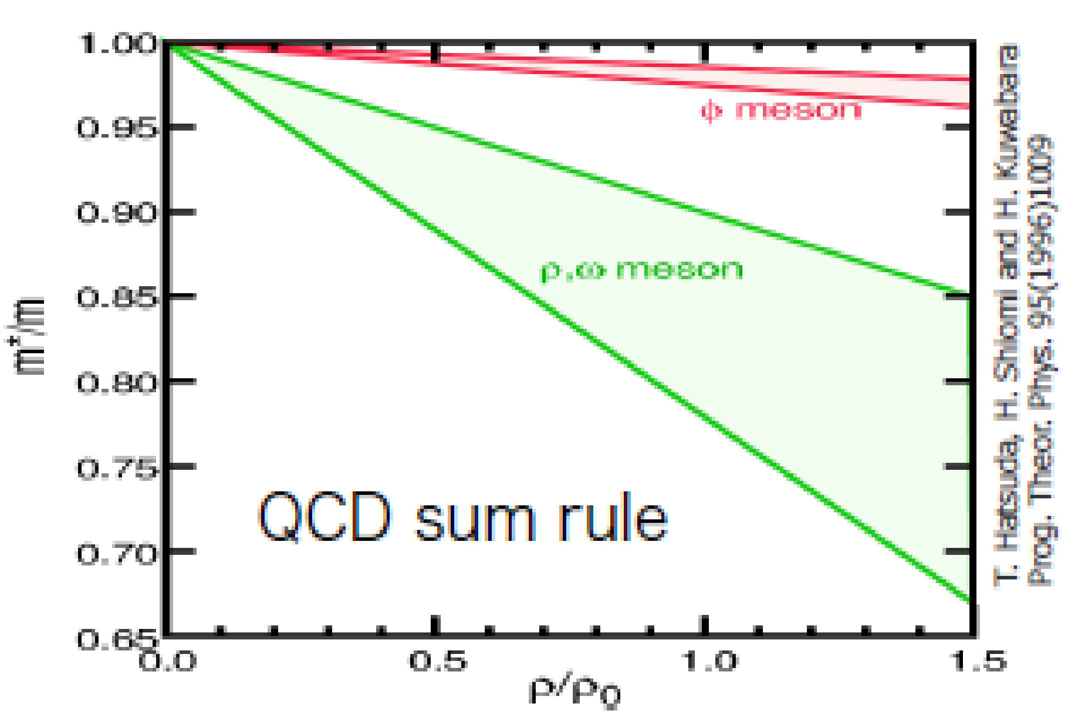
W. Weise, NPA553, 59(1996)



Spontaneous Chiral Symmetry Breaking

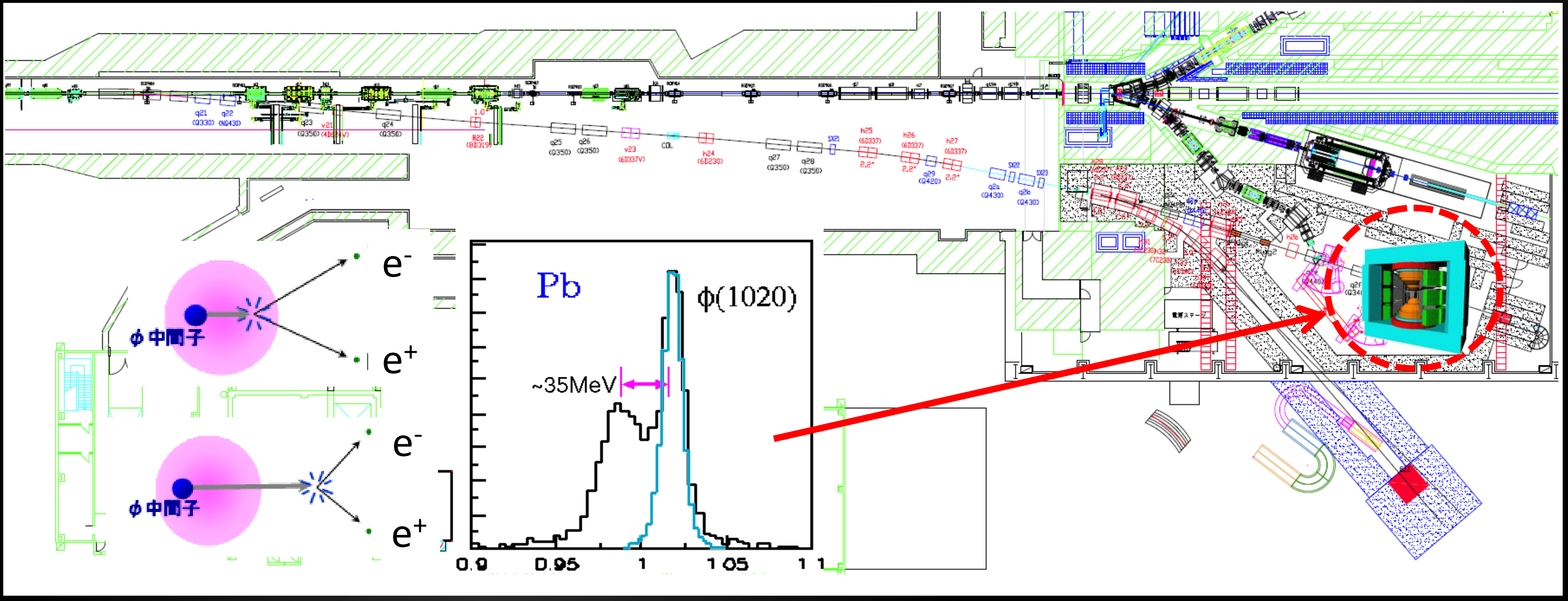
- Spectral changes of vector mesons in nuclear matter

  T. Hatsuda, H. Shiomi, and H. Kuwabara, PTP95, 1009(1996)



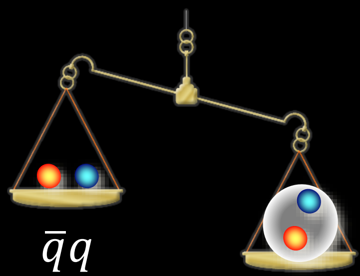
Vector meson in Nuclear Medium
E16 Experiment at the High-p Beam Line

- Branch from the main primary BL-A line
  - 10^{10} primary proton at 30 GeV
- Commissioning will start in FY2018

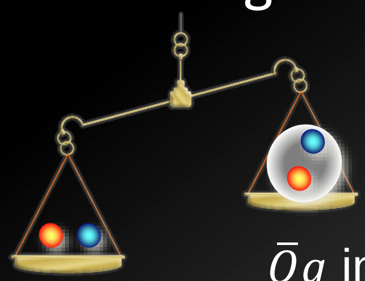


Property changes of Hadrons in Matter:

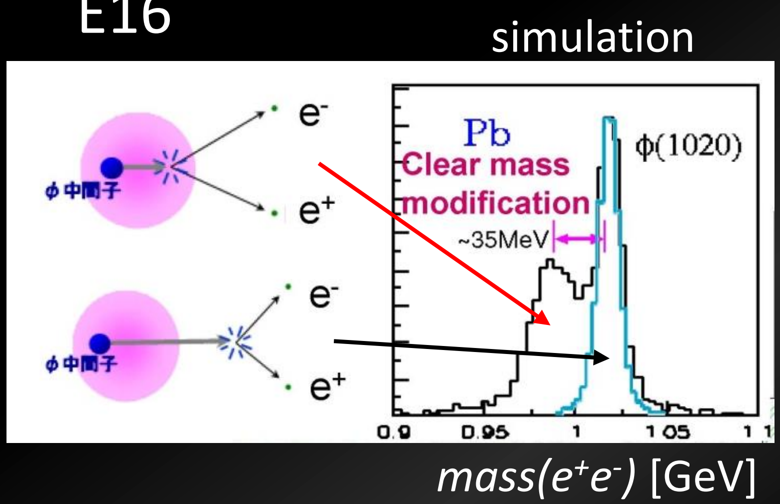
- Vector meson ($\bar{q}q$): ϕ, ω, ρ
  - Mass: decreasing in matter

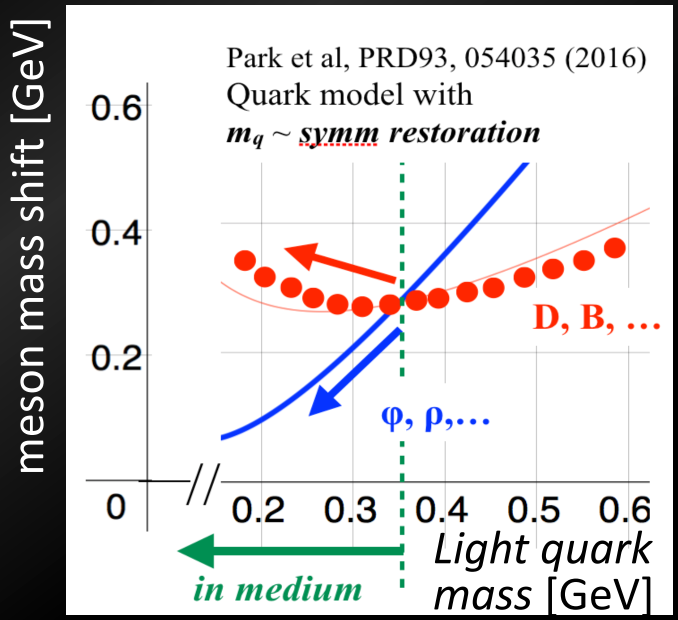


- Open charm meson ($\bar{Q}q$): D
  - Mass: increasing in matter ?

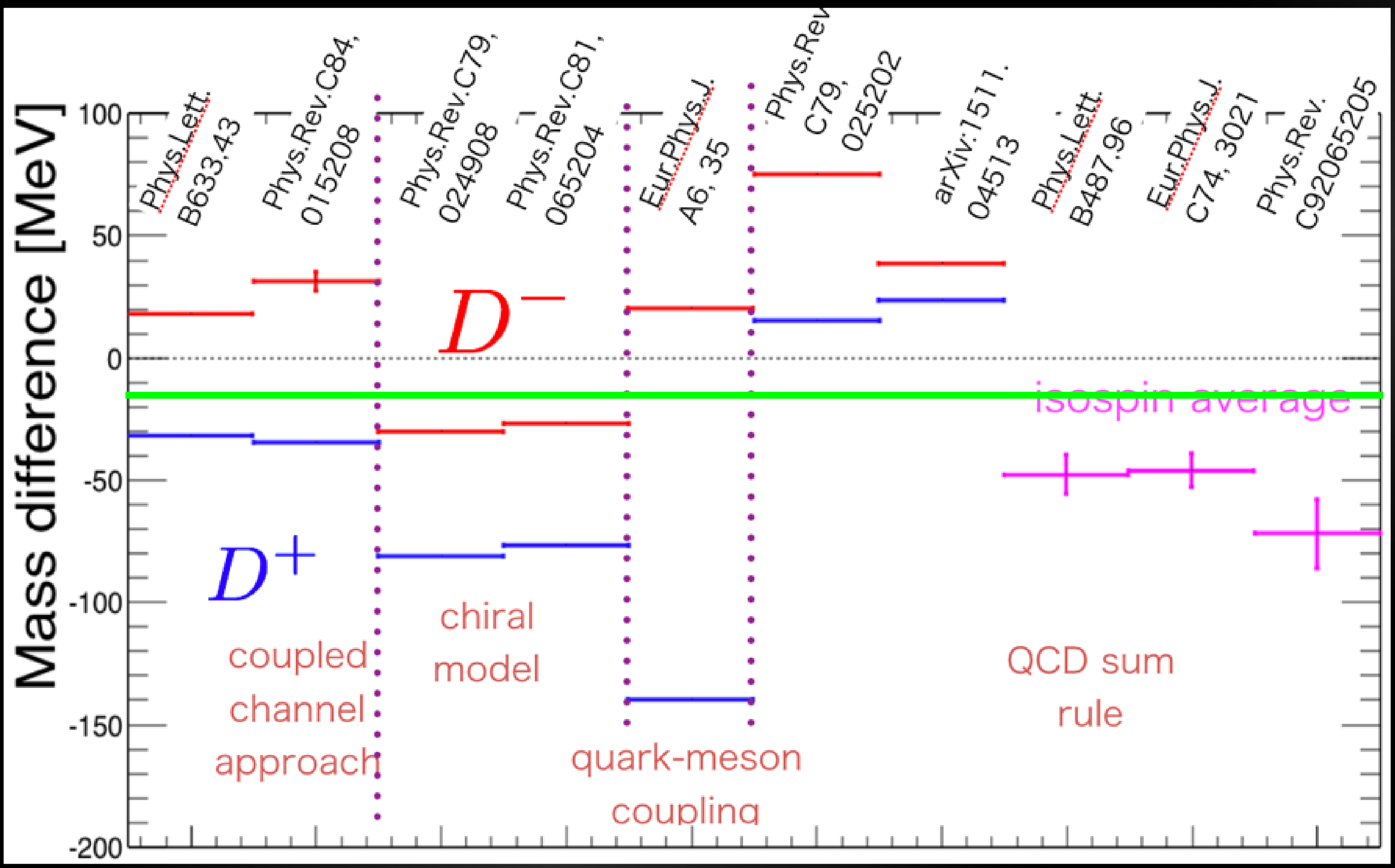


E16



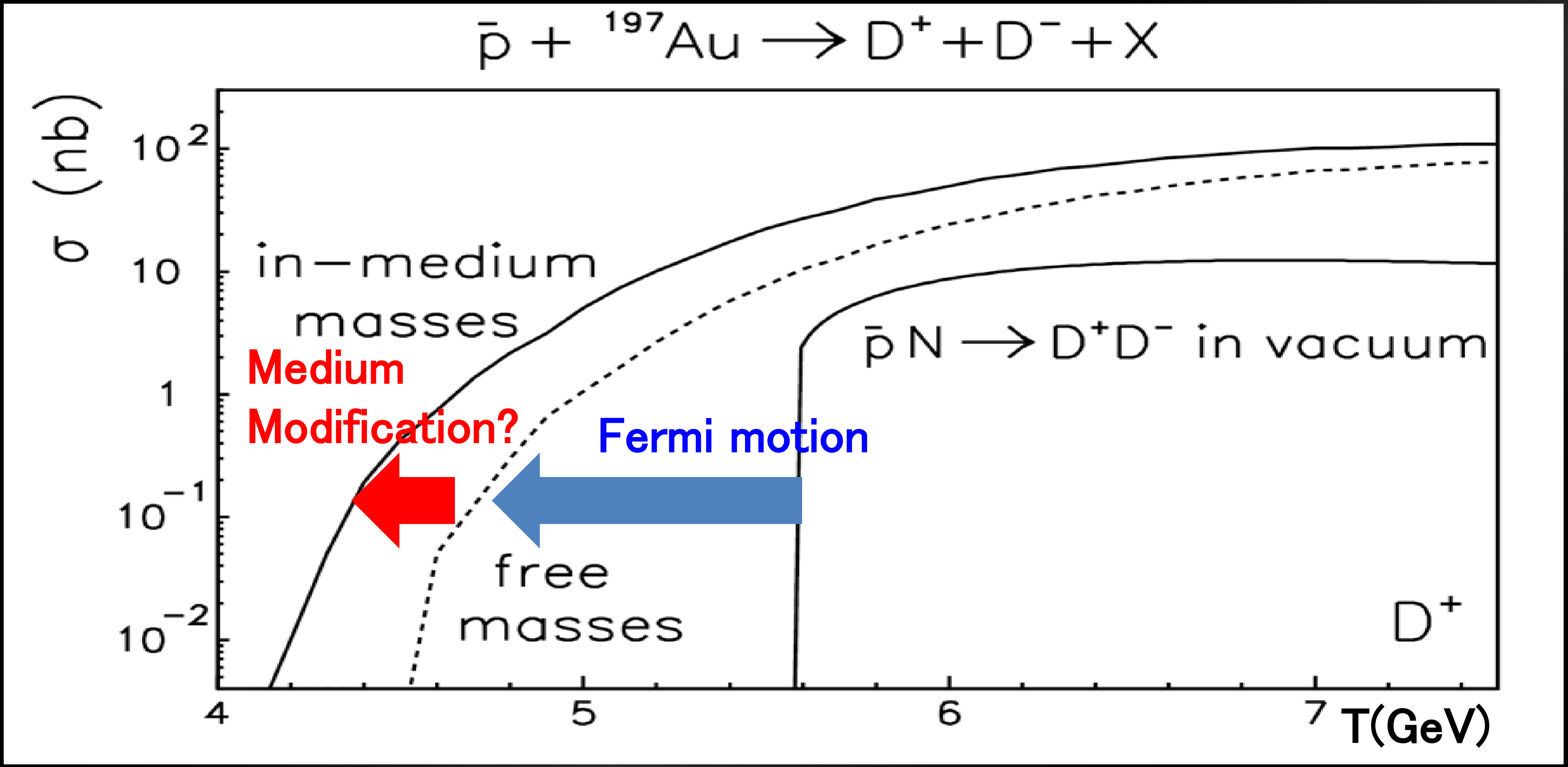


D Mesons in Nuclear Medium



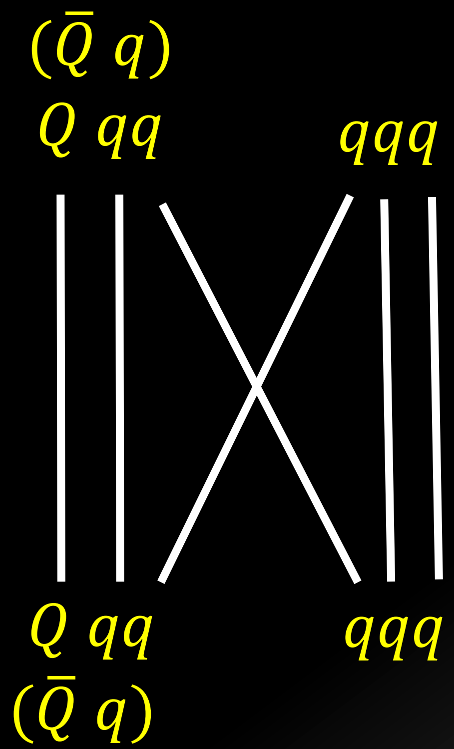
How to observe the effect?

Sub–threshold enhancement of D^+/D^- production on pbar–A interaction (Euro.Phys.J A,351)



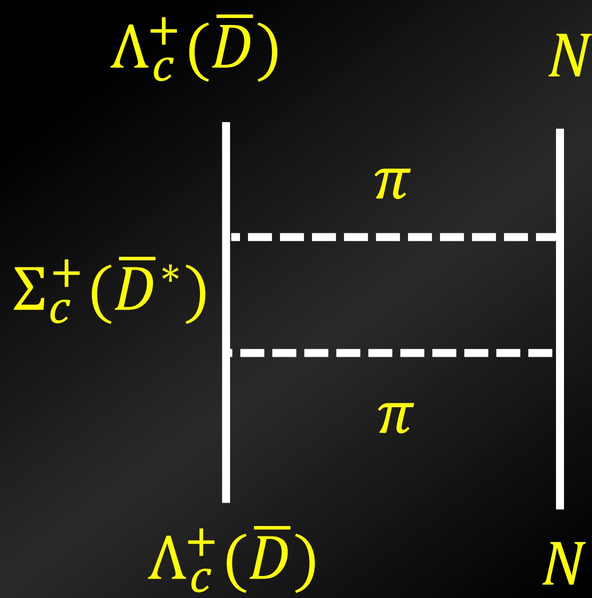
What happens if D^-/Λ_c^+ sticks in Nucleus?

- Short range



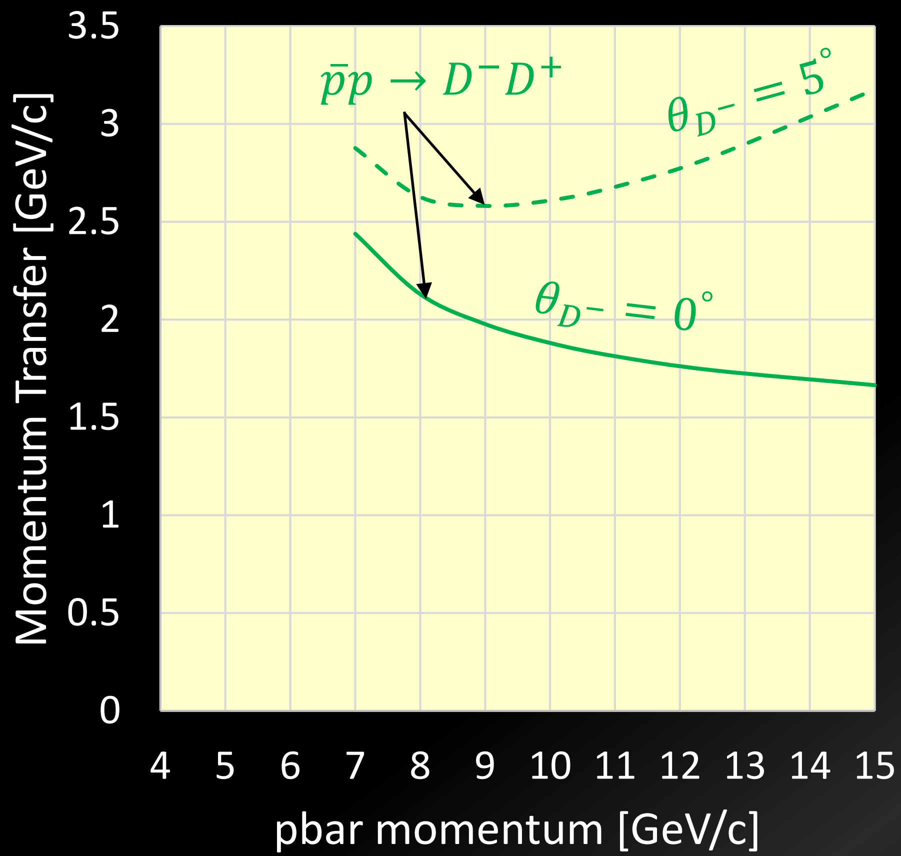
Quark Dynamics

- Long range



Heavy Quark Symmetry

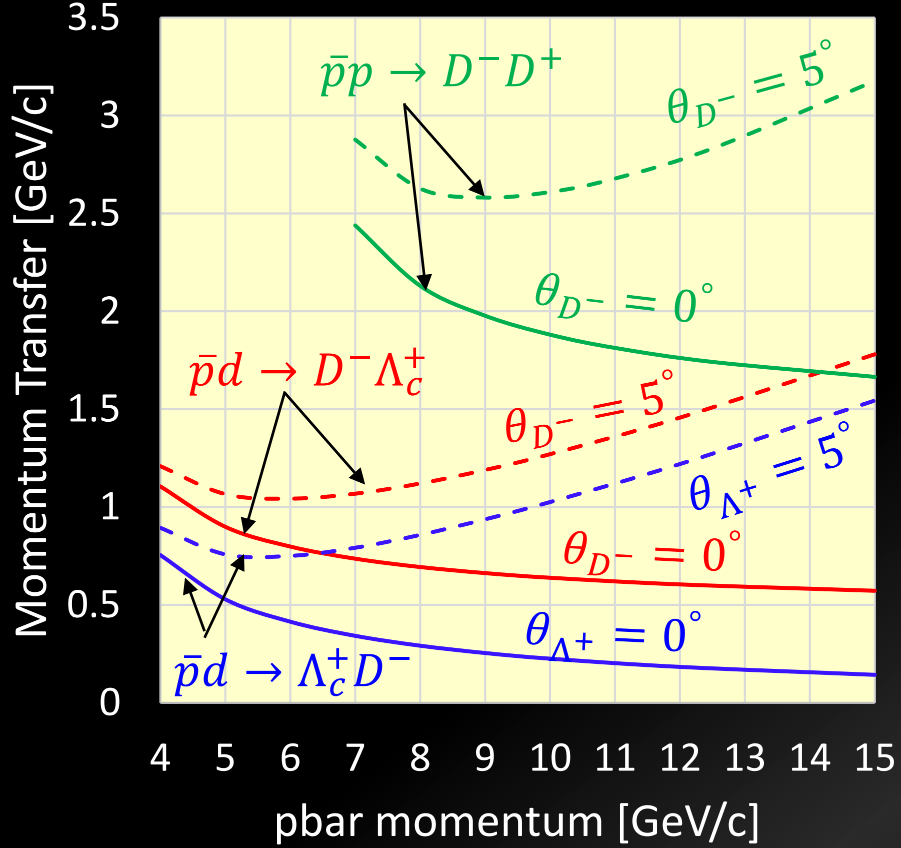
Can We Stick D^{+}/Λ_c^{+} in Nucleus?



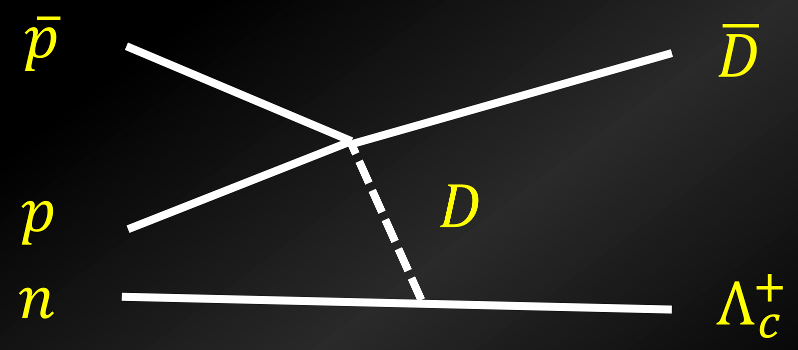
- $\bar{p}p \to D^{-}D^{+}$

Recoil momentum is too far beyond the Fermi-momentum...

Can We Stick D^+/Λ_c^+ in Nucleus?



- $\bar{p}d \to D^-\Lambda_c^+$



- $\bar{p}A \to D^- + {}_{\Lambda_c}A'$

  $\to \Lambda_c^+ + {}_{\bar{D}}A''$

Problem: How small is the C.S. ?

Facility: K10

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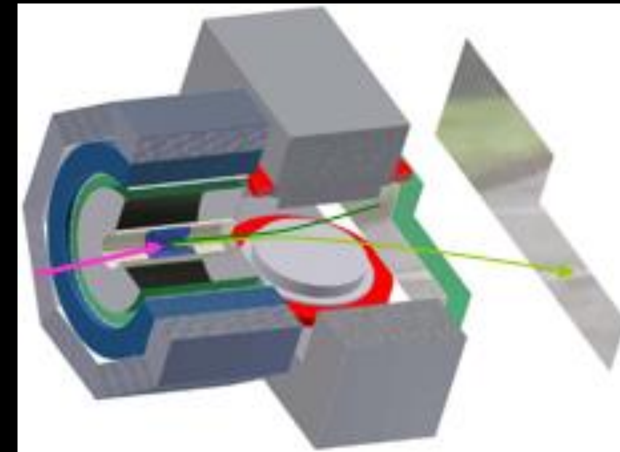
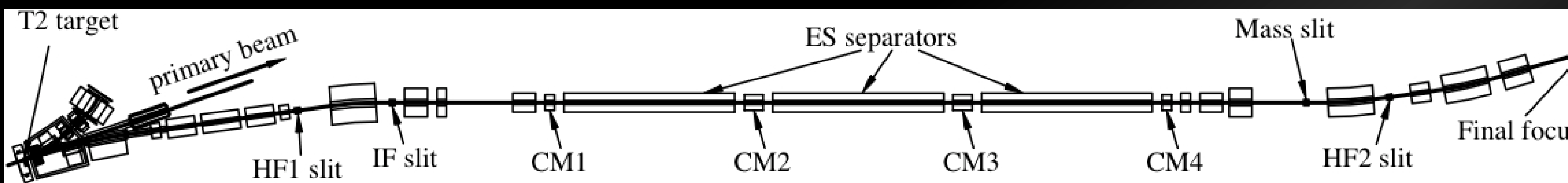
- 3-stage electro-static separators:
  - 9 m each, 75kV/cm
- Length : 82.8 m





25 kW loss@T2 target

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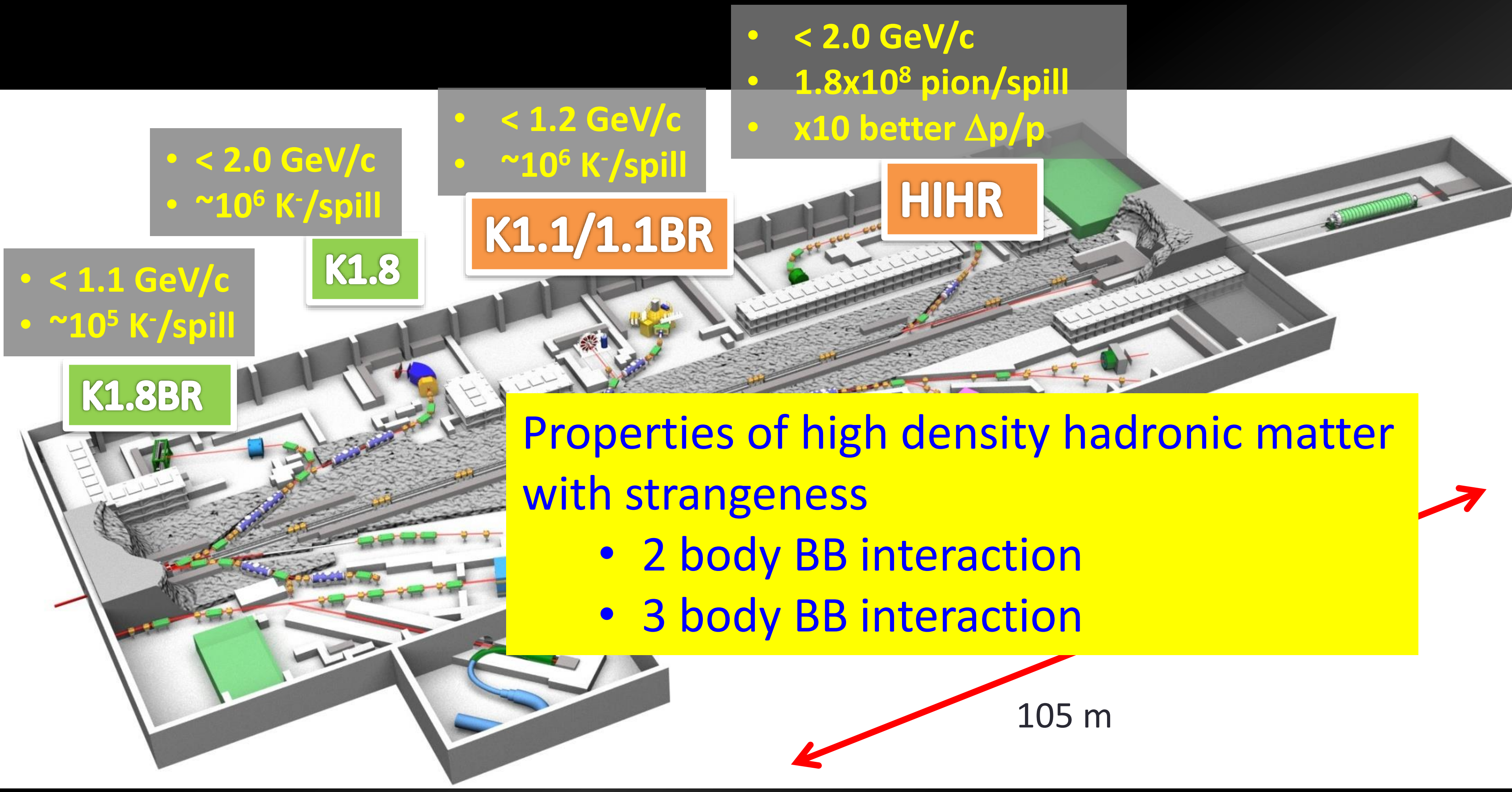
Purity	1.1:1	81:1	1:3.4

Nuclear Physics Program



Properties of high density hadronic matter with strangeness

- 2 body BB interaction
- 3 body BB interaction

Issue in Nuclear Physics

- To understand hadronic matter, in particular, at high density…

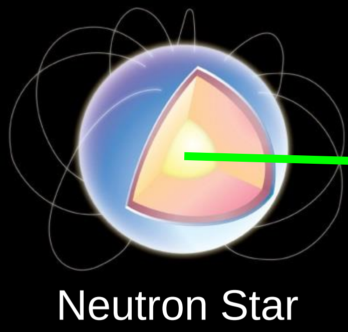
$$\frac{E}{A}(\rho) = 2BF(\rho) + 3BF(\rho) + 4BF(\rho) + \cdots$$

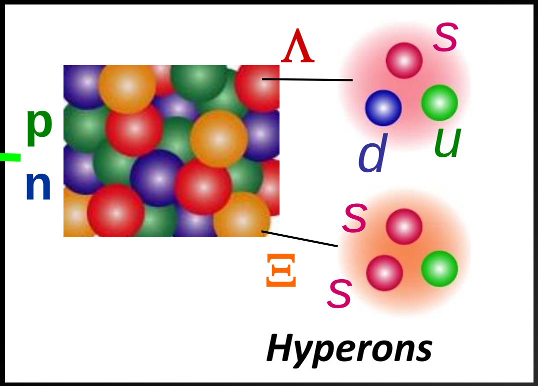
Though the nuclear density is hardly controlled with keeping low temperature in experiment…

- Heavy neutron stars may provide the touchstone.
- Need to refine knowledge on nuclear forces:
  - More reliable BB interaction
  - Effects of multi-body forces

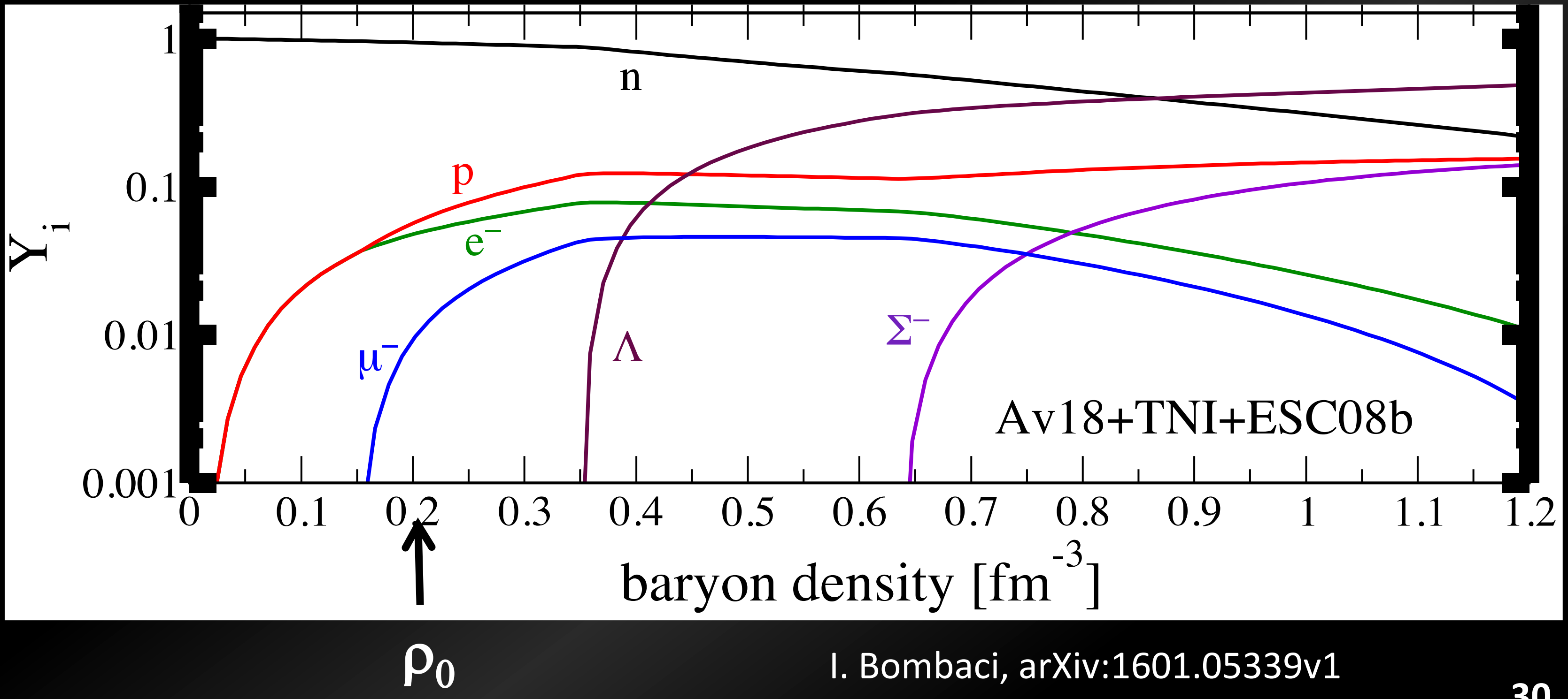
High Density Hadronic Matter

Hypernuclear Physics tells:
The NS core is likely to
contains hyperons.





Theoretical prediction from known YN, YY 2-body interactions (Y=hyperon)

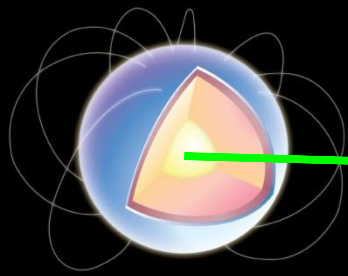


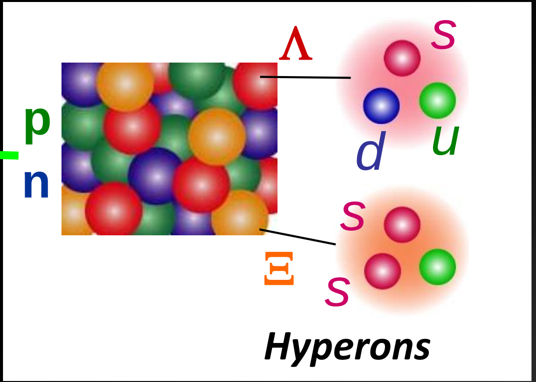
I. Bombaci, arXiv:1601.05339v1

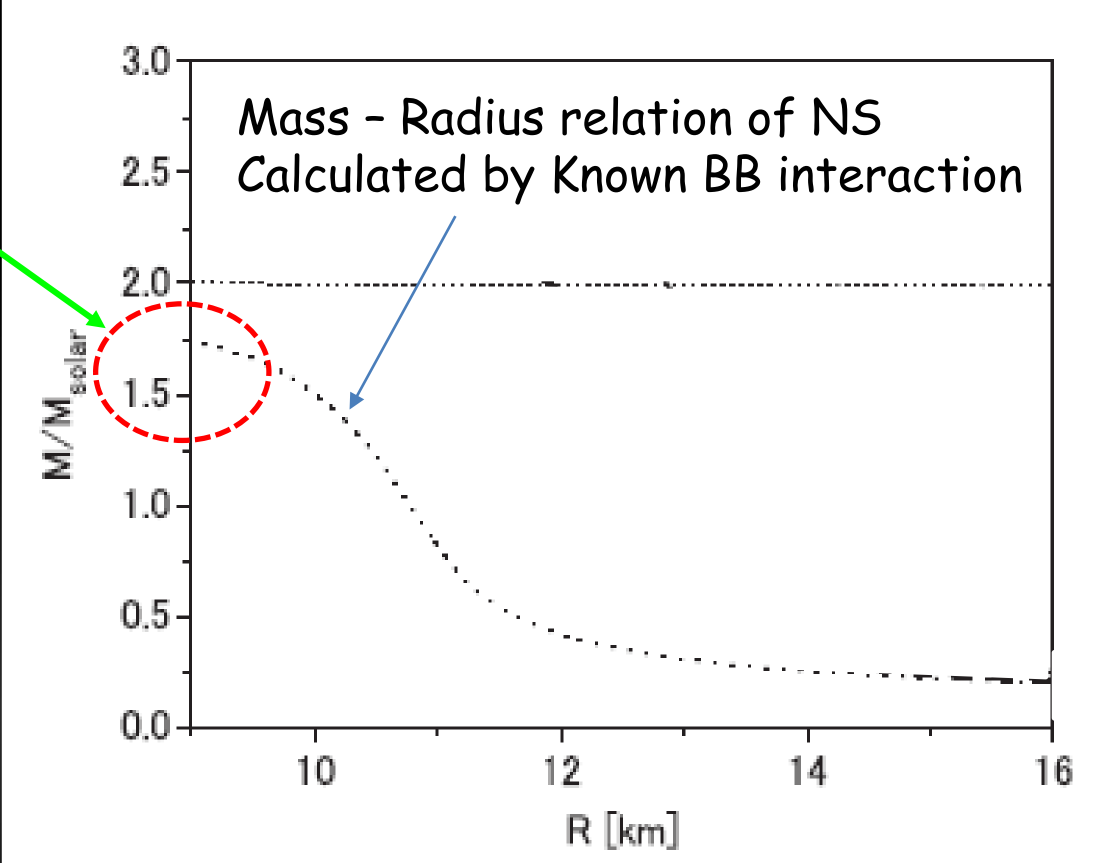
High Density Hadronic Matter

Hypernuclear Physics tells:
The NS core is likely to
contains hyperons.

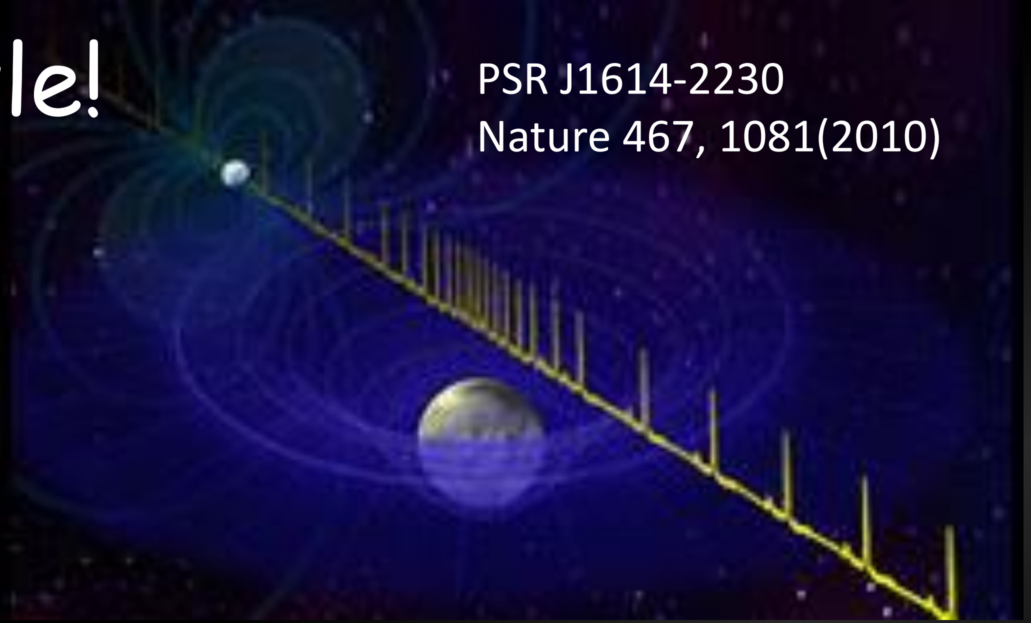
makes the EoS soften.
Max. M_{NS}~1.5 M_{solar}







Neutron star puzzle!



PSR J1614-2230
Nature 467, 1081(2010)

Hypernuclear Physics tells:
The NS core is likely to
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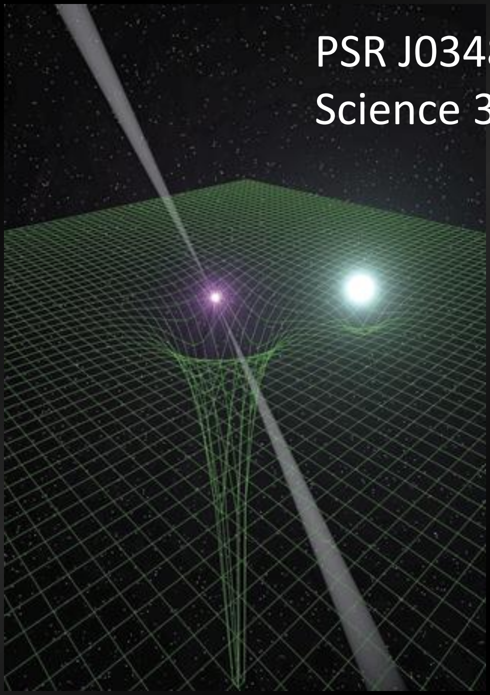
↓

makes the EoS soften.
Max. M_{NS}~1.5 M_{solar}

↕

Observation:
Max. M_{NS} ~ $2M_{solar}$



PSR J0348+0432
Science 380, 1233232(2013)

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↕

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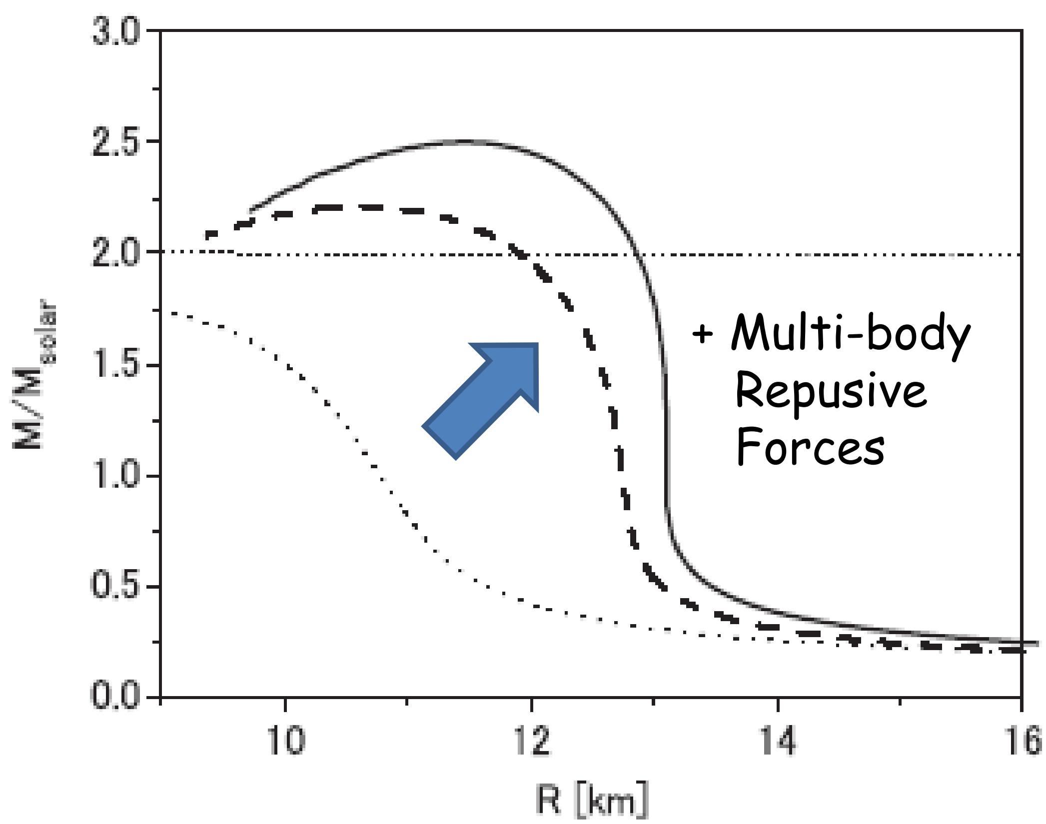
↓

Universally-working,
repulsive forces (URF)
among 3/4 baryons ?

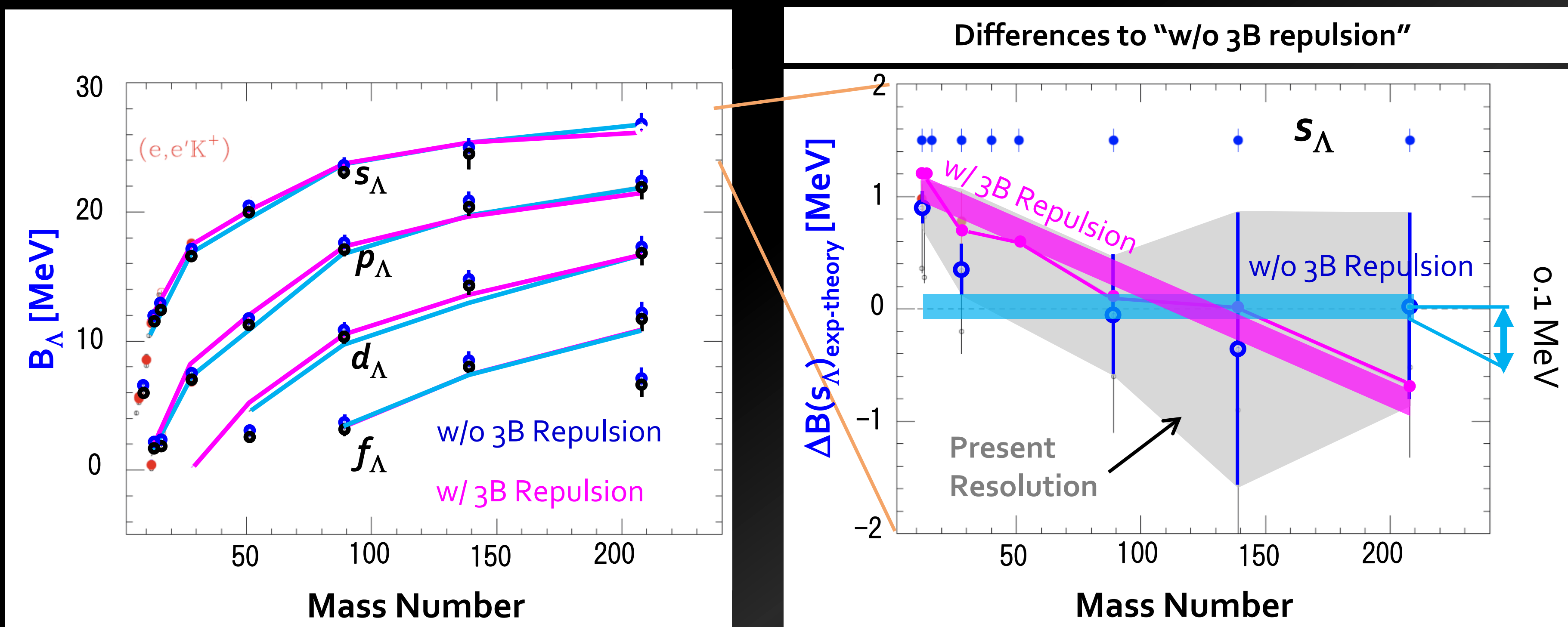


High Density Hadronic Matter

through high precision (π,K⁺) spectroscopy

- ΛNN 3-body force; attractive in long range, repulsive in short range ?

Binding Energy ($B(s_\Lambda)$) difference with/without 3 body repulsion ~±0.5 MeV



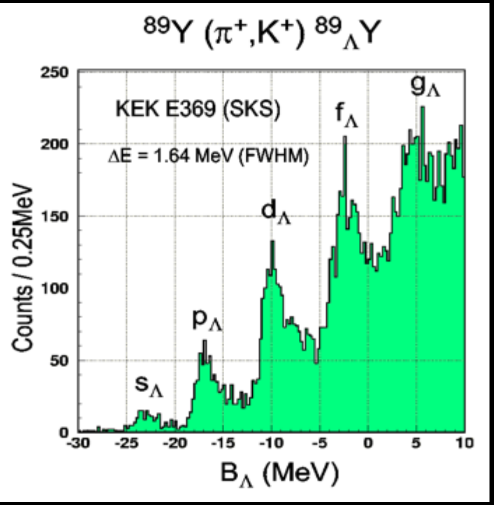
Mass dependence (=density dependence) of $B(s_\Lambda)$ reveals strength of the 3-body repulsion force. ΔE~0.1 MeV measurement is required to verify 3-body repulsion and to solve the Hyperon Puzzle.

High Density Hadronic Matter

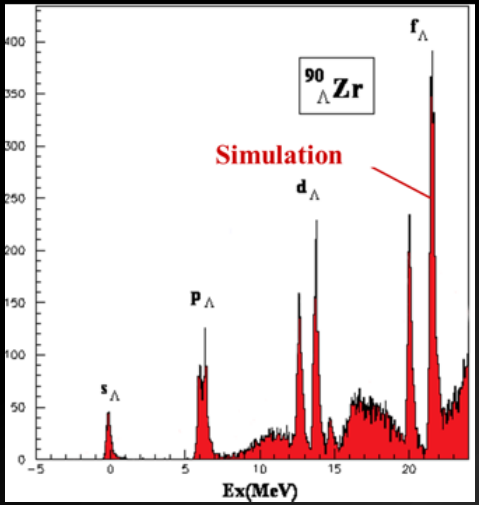
through high precision (π,K$^+$) spectroscopy

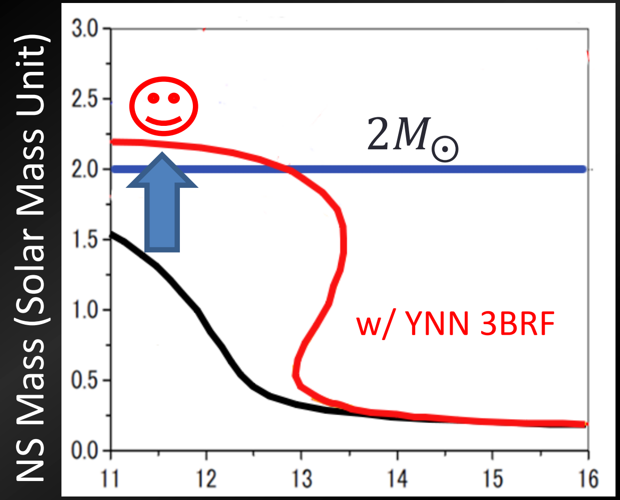
- ΔE~0.1 MeV measurement with (π,K+) at High-Intensity High-Resolution BL

KEK-PS E369 with SKS



Expected at HIHR beam line





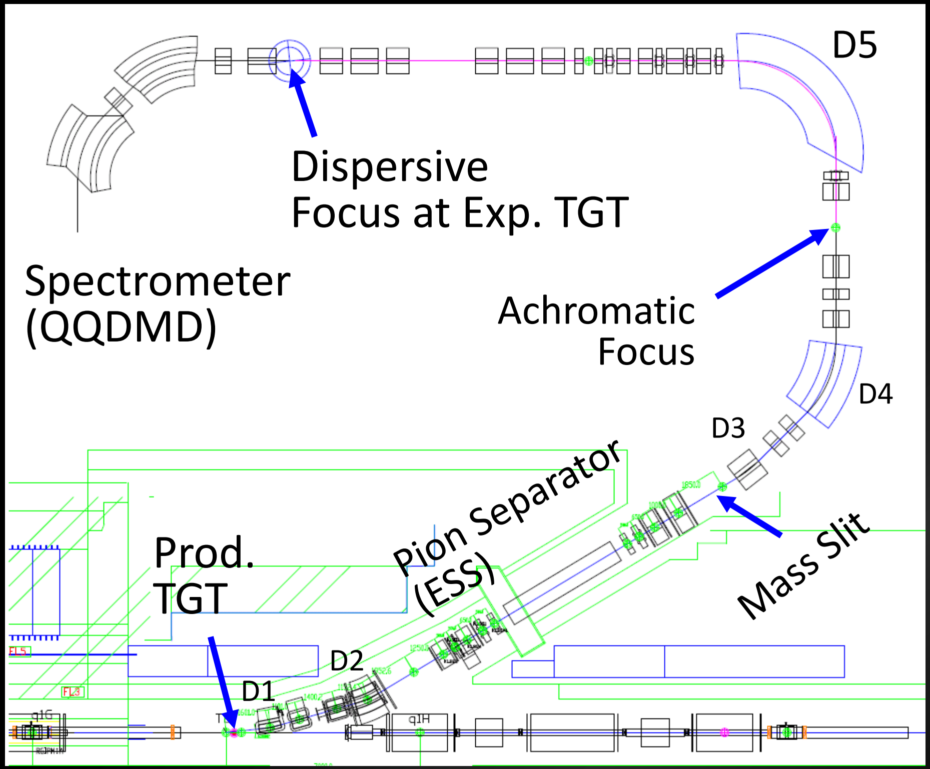
Neutron Star Radius (km)

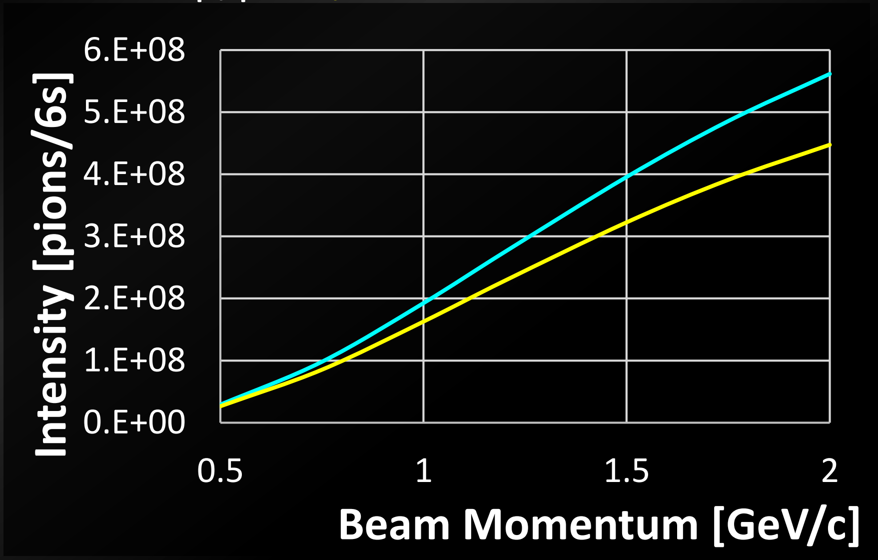
Facility: HIHR

Present beam lines:
~10^6 pions/pulse, $\Delta p/p$ ~ 1/1000

- High-Intensity High-Resolution Beam line
for High Precision (π, K^+) Spectroscopy in ΔE=0.1 MeV
  - Dispersion matching ; no beam tracking
(well established tech.)

Intensity: ~ 2.8×10^8 pion/pulse
(1.2 GeV/c, 58 m, 1.4msr*%,
50kW, 6s spill, Pt 60mm)
$\Delta p/p$ ~ 1/10000





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$$\frac{E}{A}(\rho) = 2BF(\rho) + 3BF(\rho) + 4BF(\rho) + \cdots$$

Though the nuclear density is hardly controlled with keeping low temperature in experiment…

- Heavy neutron stars may provide the touchstone.
- Need to refine knowledge on nuclear forces:
  - More reliable BB interaction
  - Effects of multi-body forces

Latest BB interaction

ESC

↓

G-Mat.

↓

U_Y

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Λ	$U_{\sigma\sigma}$
ESC08c	−13.1	−26.5	2.4	0.1	1.1	−3.1	−1.6	−40.8	1.07
ESC08c$^+$	−12.6	−25.4	2.9	0.3	1.6	−2.1	−2.3	−37.6	1.03

model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ
ESC08c	1/2	11.1	−22.0	2.4	2.1	−6.1	−1.0	−0.7	
	3/2	−12.8	30.7	−4.8	−1.8	6.0	−1.4	−0.2	+1.4
ESC08c$^+$	1/2	11.1	−20.4	2.6	2.1	−5.8	−0.6	−0.8	
	3/2	−11.9	31.8	−4.2	−1.6	6.4	−0.4	−0.6	+7.9

model		$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ	Γ^c_Ξ
ESC08c	$T=0$	1.4	−8.0	−0.3	1.8	1.4	−2.1		
	$T=1$	10.7	−11.1	1.1	0.7	−2.6	−0.0	−7.0	4.5

arXiv:1501.06636
arXiv:1504.02634

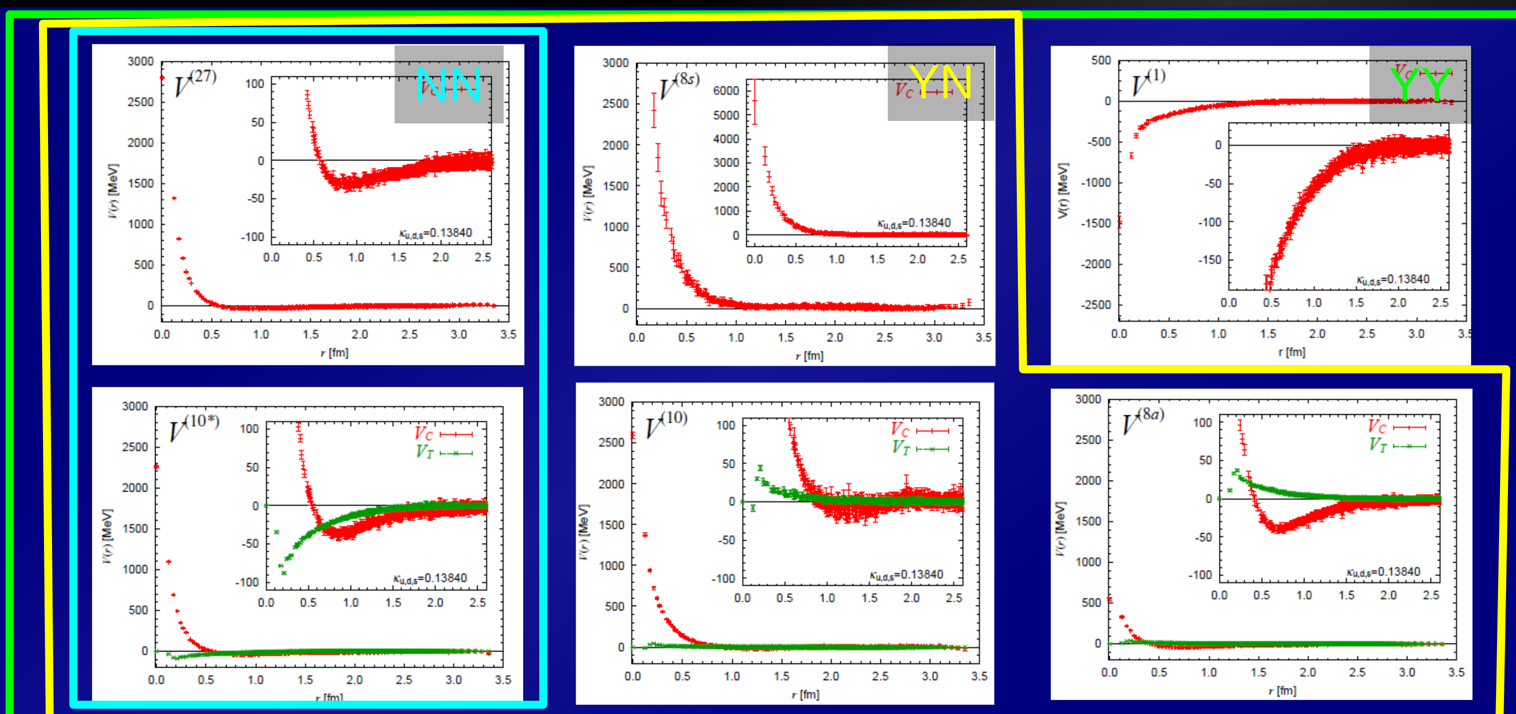
LQCD

m_π =145 MeV

$SU_F(3)$

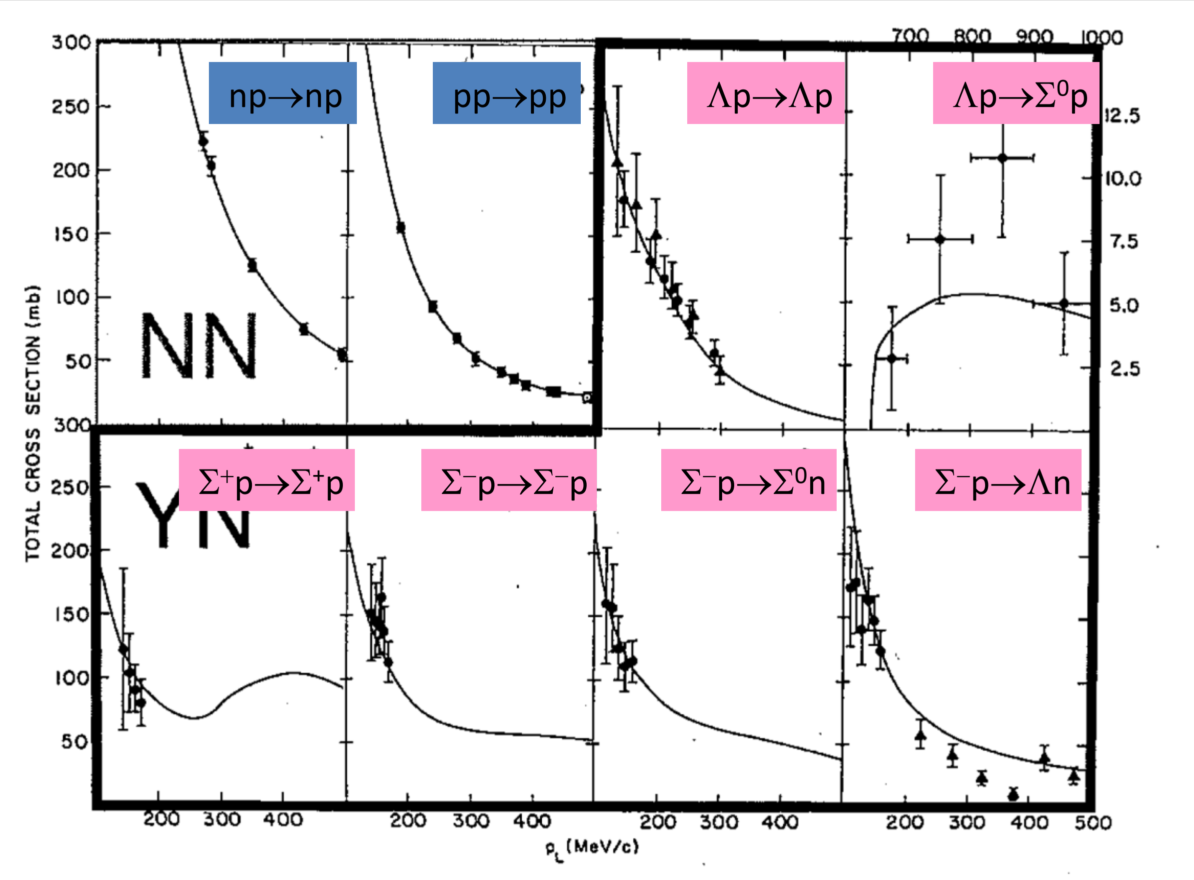
B_8xB_8

Nucl.Phys. A881(2012)28



YN Data is still very poor.

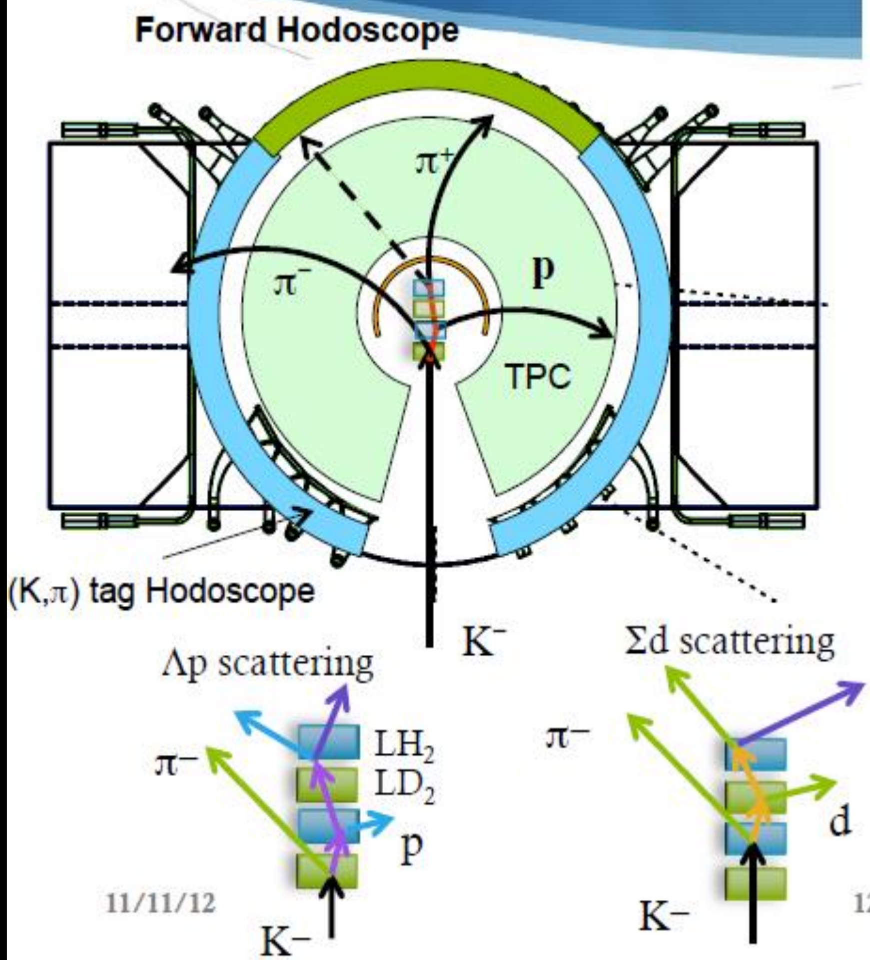
- Insufficient $d\sigma/d\Omega$: Short range part (high-p)
  - Lack of $P^*d\sigma/d\Omega$: Λp, Σ^+p Spin-Orbit Int.
    - Yd : 3B int.



Idea of experimental setup

at K1.1

K. Miwa et al.(Tohoku U.)



- Requirement for spectrometer
  - (K^-, π^-) reaction with large reaction angle should be detected.
  - All charged particles of Yp scattering should be detected

Tracking detector system in spectrometer magnet

LH_2-LD_2 Target

Λ beam production : $K^- n \rightarrow \pi^- \Lambda$ @ LD2

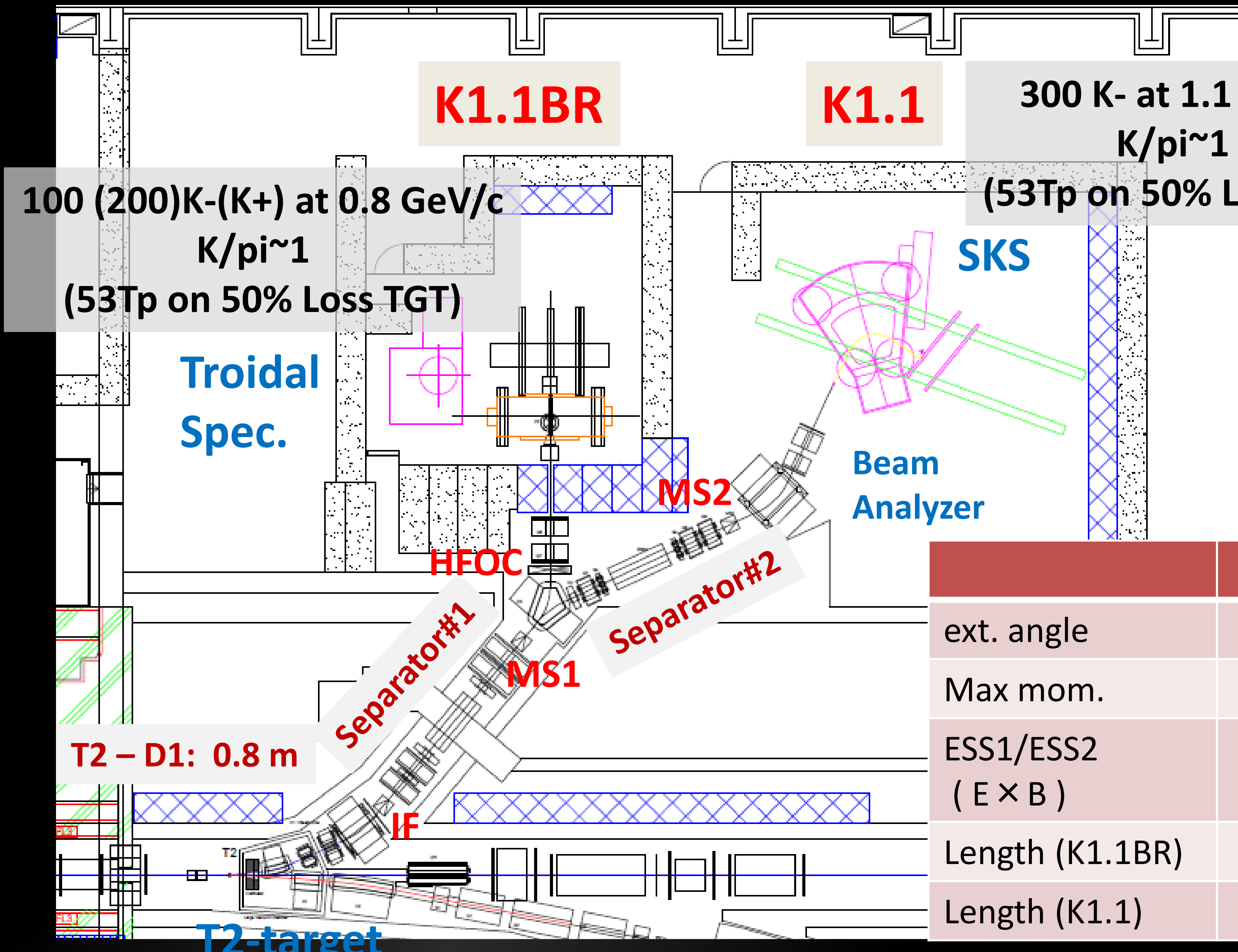
$\Sigma^\pm$ beam production : $K^- p \rightarrow \pi^- \Sigma^+$

$K^- p \rightarrow \pi^+ \Sigma^-$ @ LH2

Yp scattering @ LH2

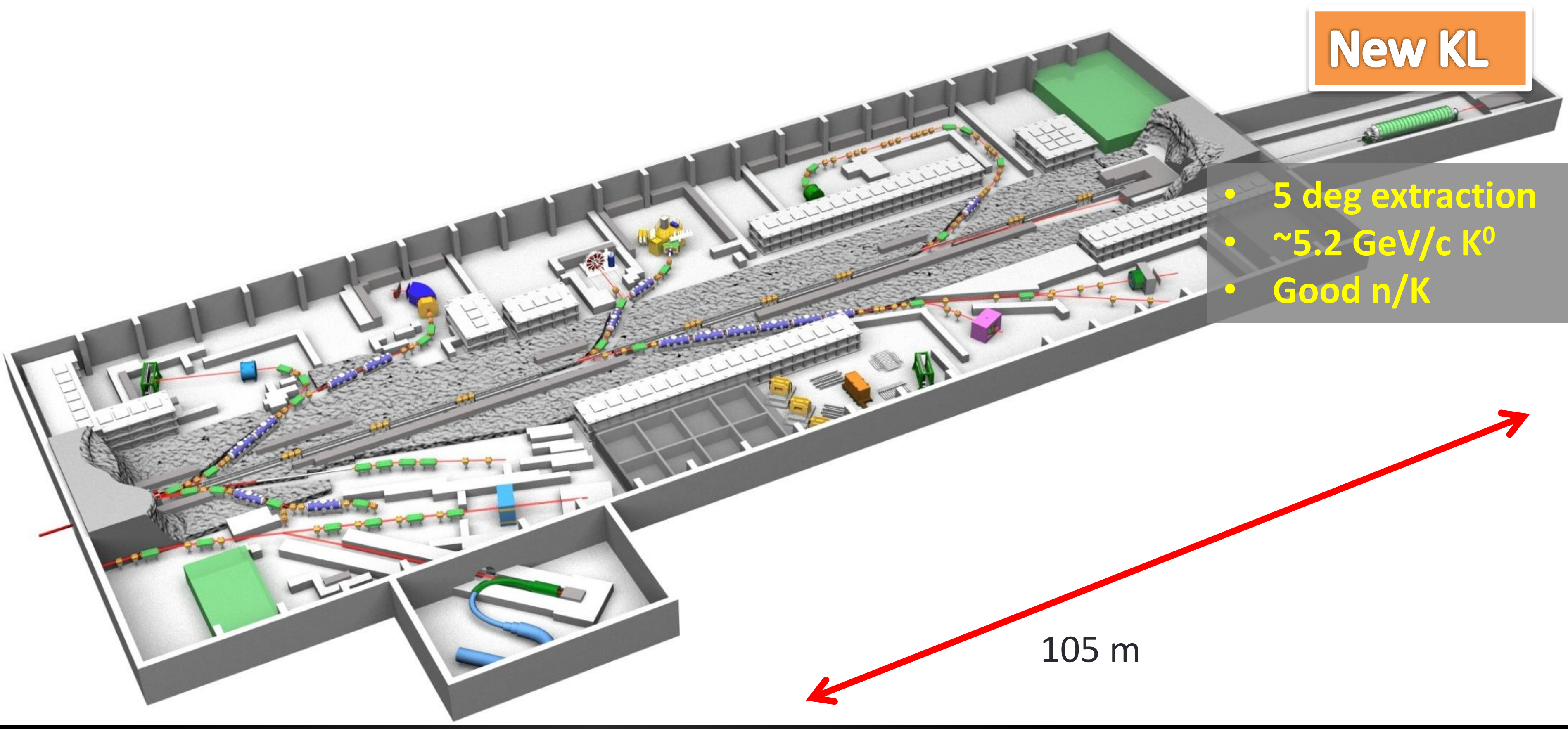
Yd scattering @ LD2

K1.1 and K1.1BR Beam Lines



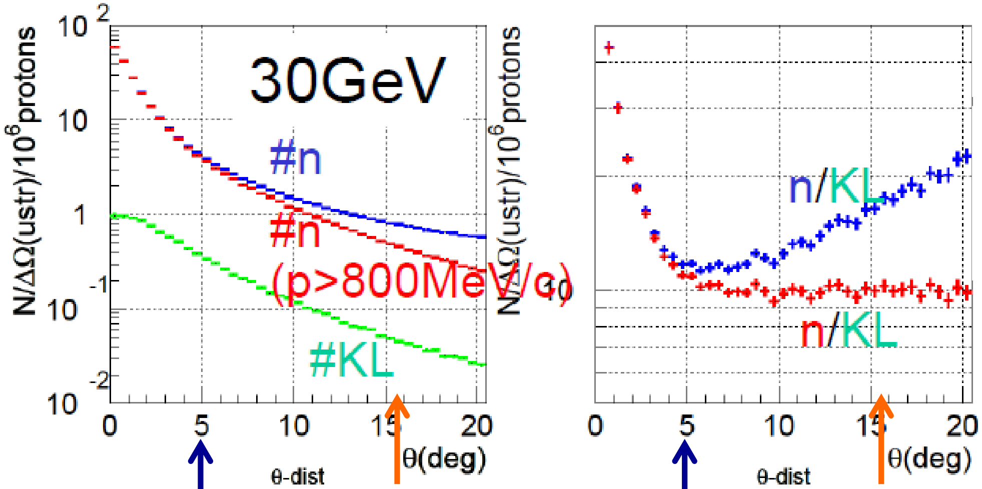
ext. angle	6 °
Max mom.	1.2 GeV/c
ESS1/ESS2 (E × B)	1.88 m, 75 kV/cm
Length (K1.1BR)	20.78 m
Length (K1.1)	28.32 m

Particle Physics (KOTO 2)



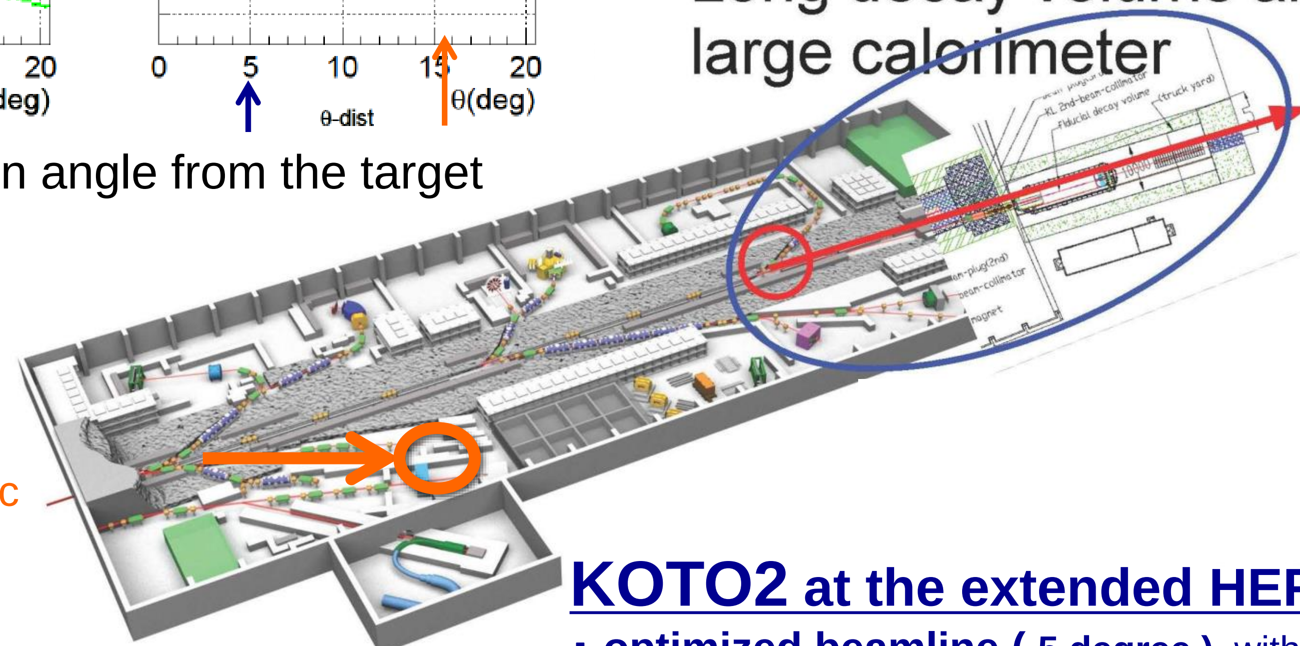
- 5 deg extraction
- ~5.2 GeV/c K^0
- Good n/K

New Facility for the new, upgraded experiment



Extraction angle from the target

- neutral beam: 5 degree
- area: just behind the dump
  ~50m from the target
  - Long decay volume and large calorimeter



KOTO

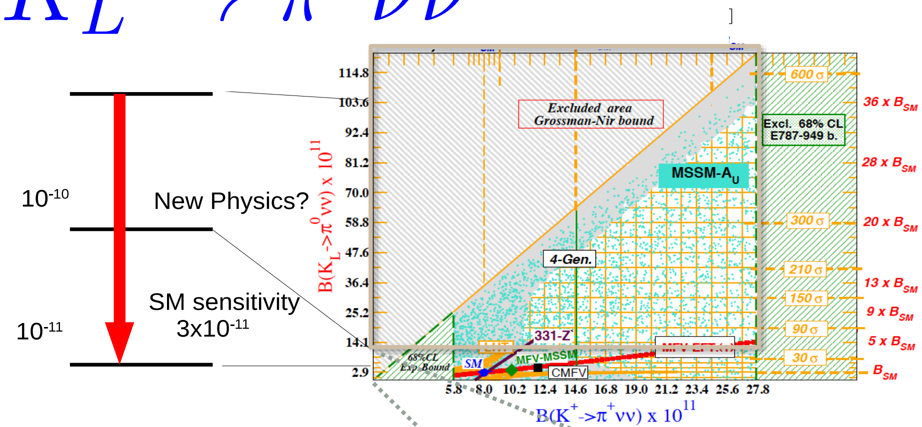
neutral beam: 16 degree
- KL momentum ~ 2.1GeV/c

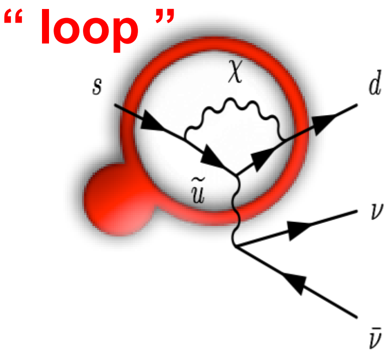
KOTO2 at the extended HEF:

- **optimized beamline (5 degree)** with
  - larger KL momentum （ ~5.2GeV/c ）
  - more KL flux （ x6 ）
  - minimum neutron ratio (n/KL=5)
- **large-acceptance new detector**
  can be accommodated to the new area

Search for physics beyond the Standard Model

$K_L \to \pi^0 \nu \overline{\nu}$



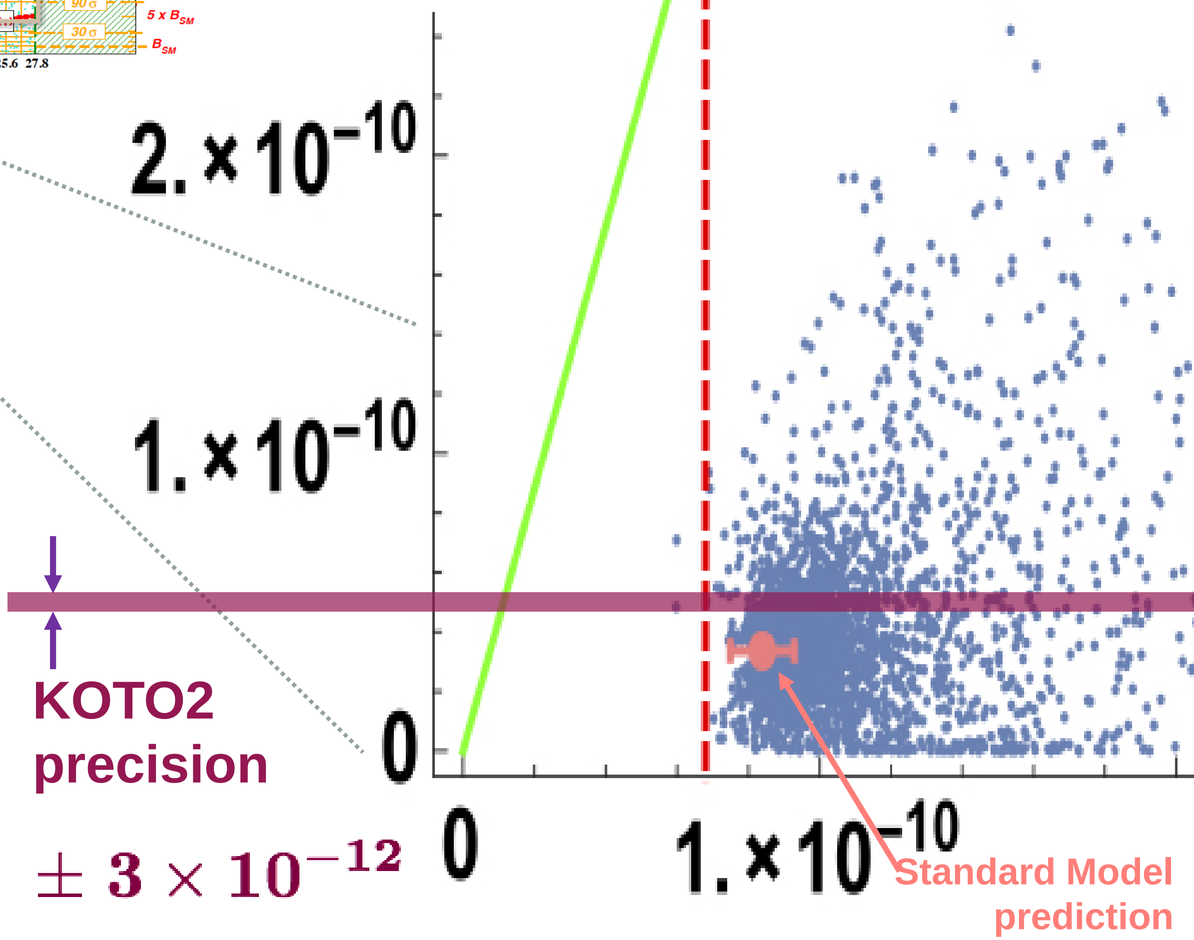


example:
effects of
new
SuperSymmetric
particles
at 10 TeV

The new KOTO2 at the extended HEF

will reach the sensitivity
to measure
the branching fraction
(10% in the case of SM only)

and
to observe
the deviation from the SM
and discover
New Physics effects.



Many Important Subjects are lined up

- Hypernuclear Weak Decay (Botta et al., Feliciello et al.)
  - Short lifetime problem : $\tau({}^{3}_{\Lambda}H, {}^{4}_{\Lambda}H) < \tau(\Lambda)$
- Hypernuclear Magnetic Moment (H. Tamura et al.)
  - Change of Hyperon Property in Matter
- Σ hypernuclei
  - Coulomb Assisted Hybrid Bound State
- ΞN, ΩN, ${}^{A}_{\Xi}Z$, ${}^{A}_{\Omega}Z$: K1.8/K10 (H. Takahashi et al.)
- η-, η'-meson in nucleus
  - $A(\pi^{+},p)_{\eta(\eta')}D$ (K. Itahashi, H. Fujioka et al.)
  - restoration of ChSB
- Exotic atom/nuclei
  - Kaonic X-ray w/ Ultra-high Res. (S. Okada et al.)
    - K-A int., Fundamental Physics
  - ${}^{4}He(\pi^{-},\pi^{+}){}^{4}n$ (H. Fujioka et al.)
- Recent Reference:
  - **Int. WS on Phys. at the Extended Had. Exp. Facil. of J-PARC: https://kds.kek.jp/indico/event/20472/**

In Summary…

- The project is listed up in a “Roadmap 2014”, a basic plan for large-scale academic projects to be promoted under MEXT
- KEK recently implanted a priority to this project.
- Physics opportunities will be expanded by Extended Hadron Hall at J-PARC.